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MINISTRY OF FUEL AND POWER

FUEL
AND THE FUTURE

The Proceedings of the Conference held in London on October 8th, 9th and 10th, 1946, under the Auspices of the Fuel Efficiency Committee.

VOLUME TWO

LONDON
HIS MAJESTY'S STATIONERY OFFICE
1948

PREFACE

The general need for efficiency in British industry has never been greater than it is to-day. Fuel efficiency is an integral part of production efficiency, and correct fuel utilisation is now, and will be in the future, essential in every factory, establishment and home. For this reason, the Fuel Efficiency Committee of the Ministry decided in March, 1946, to convene a conference at which both the present state of development of fuel utilisation and its future trends could be freely discussed by experts in each individual field in an informative manner for the general guidance of all fuel users, industrial and domestic.

Nearly five thousand industrialists and members of domestic organisations interested in fuel usage attended the conference on 8th, 9th and 10th October, 1946.

After a joint opening session at which those assembled were addressed by prominent members of the Government, Industry and Trade Unions, the conference divided into eight sections meeting simultaneously in different places, each section holding three sessions consecutively. The sections dealt with the following subjects :

Section " A "—The Generation of Steam.
Section " B "—Steam Utilisation.
Section " C "—Heat for Drying.
Section " D "—High Temperature Processes.
Section " E "—The Carbonisation and Chemical Industries.
Section " F "—Special Industrial Sessions.
Section " G "—Modern Heating and the Architect.
Section " H "—The Home and its Fuel Services.

Two joint sessions were then held simultaneously, one dealing with the Sizing and Grading of Coal, and the other with District Heating, after which there was a closing session presided over by the Rt. Hon. Emanuel Shinwell, M.P., Minister of Fuel and Power, and addressed by the Rt. Hon. Sir Stafford Cripps, K.C., M.P., President of the Board of Trade, at which also the sectional chairman summarised the conclusions of their meetings.

The proceedings of the conference have been printed in three volumes, of which this book comprises the second. It is devoted to sections D, E and F dealing with high temperature processes, the carbonisation and chemical industries, the light and heavy clay industries, the railways and the coal industry. In addition it includes the joint session on the sizing and grading of coal.

Considerations of space have made it necessary to curtail most of the communications to a greater or lesser extent by abridgement, summarisation or condensation as best fitted the subject. Every care has been taken to avoid the omission or distortion of any essential matter, and the authors are thanked for submitting to this unfortunately necessary operation.

Where requested, acknowledgments have been formally made in the text of this publication. In addition, the Ministry wish to express their thanks to all those who have contributed to the success of this conference and without whose aid it could not have been held.

Finally, it should be pointed out that the fact of publication of these proceedings must not be held to imply that all the views expressed therein are necessarily in every respect those of the Ministry of Fuel and Power.

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HIGH TEMPERATURE PROCESSES

Chairman: DR. R. J. SARJANT, O.B.E.

CHAIRMAN OF THE EDUCATION SUB-COMMITTEE OF THE FUEL EFFICIENCY COMMITTEE, LOCAL DIRECTOR OF MESSRS. HADFIELDS, LTD.

SESSION I. The Scope for Savings

Chairman of Session: DR. C. H. DESCH, F.R.S.

PRESIDENT OF THE IRON AND STEEL INSTITUTE

THE session opened with statements by the Presidents of the Iron and Steel Institute, The Institute of Metals and the Society of Glass Technology.

THE CHAIRMAN, **Dr. C. H. Desch,** said that when considering figures given for average overall savings many works were more successful than the published figures showed.

The metallurgical industry developed at an early date when fuel was cheap and, representing only a small fraction of the value of the finished material, was therefore considered unimportant. Most of the old plants were very wasteful of fuel. As an aftermath of two wars the price of fuel showed considerable increase and it became a more important factor.

Many improvements had gradually been made, e.g. the heavy smoky atmosphere considered necessary in steel annealing practice had been replaced by satisfactory combustion conditions with good effect on fuel economy.

In steelworks practice an integrated plant would show a high efficiency and little could be done to improve the blast furnace, the efficiency of which approximated closely to the theoretical figure as calculated by Sir Lowthian Bell. During the war periods blast furnaces designed for imported ores perforce had to change over to lower grade ores but even under these conditions good efficiencies had been reached.

The process of introducing carbon into iron and subsequently having to remove it had often been described as crude but all direct reduction processes so far had been failures.

The utilisation of gaseous fuels offered more scope and it was theoretically horrifying to burn raw coal. It was possible to look forward to carbonising all the raw fuel and utilising the resultant coke and by-products.

The removal of sulphur from gases was important and processes were under trial but a good field remained for research in this direction.

Flexibility as regards the type of fuel used in open-hearth furnaces was desirable.

There was considerable heat loss from the hearth and structure of furnaces and this could be reduced by insulation. Care should be taken in applying insulation because lagging increased the thermal stresses and might cause breakdown of the refractories.

Improvement in refractories was needed and tests under working conditions were required in addition to laboratory tests.

Electrical heating had been increasingly used in the ferrous industry and though the furnace efficiency was high it should be remembered that the thermal efficiency of power generation was of a low order. The overall figure should be taken into account. High-frequency melting, replacing arc melting, was now more or less general for crucible melting and a much higher efficiency was obtainable.

There was scope for substantial savings in the recovery of the low-grade heat now wasted in power-station cooling towers and in other cooling operations.

Most leading companies had established fuel research and technical staff, and the growing use of recording instruments and statistical methods would be of great value.

The Chairman concluded by pointing out that the iron and steel industry was pursuing fuel economy in the most active manner.

Col. P. G. J. Gueterbock, C.B., D.S.O., M.C. (President, Institute of Metals) : The vital importance of the metallurgical industries to the safety and well-being of the United Kingdom needs no emphasis. We all know that the industry is, of necessity, a great consumer of fuel and power and that its growth in this country has been due to our coal deposits, which in the past have yielded a supply adequate in quantity and quality and at a price which enabled us not only to smelt and fabricate metals for use in our own vast engineering industry but to export considerable tonnages of wrought and unwrought metals.

Fuel and power are the horses on which the metallurgical and engineering industries ride. " Without the horse the rider was lost " was the old proverb. Now the Minister of Fuel and Power has taken over the responsibility for providing the horses and today we are not concerned with the provision of fuel except in so far as we, the riders, are painfully aware that there are too few horses and their quality is poor. It is, even in normal circumstances, the first duty of a rider to look after his horse, and more than ever now it is incumbent on us to see that our industry uses its fuel and power to the best advantage. This conference may prove of permanent value in emphasising the necessity for a scientific approach to the problems involved in efficient utilisation of fuel.

In an industry such as ours, with its many fuel-using processes, it is essential to know with a relative amount of precision how the fuel in its various forms is used and whether it is being used effectively to produce the desired metallurgical results.

I would, therefore, at the outset stress the importance of instrumentation, sadly lacking in many quarters, and of the careful and accurate compilation of statistics and records. Without these records and statistics no-one can hope to tackle the problem scientifically or in any other than a hit-and-miss fashion.

The first question that must be answered when approaching the problem of fuel consumption is where, how and for what purpose is the fuel being consumed. It is certainly not sufficient to know merely that a certain works is consuming, say, 1,000 tons of coal weekly. Sir Arthur Smout has furnished me with some figures which illustrate this point. They refer to the average consumption of fuel in a very substantial part of the fabricating section of the industry.

	Per cent.
(*a*) Coal used for furnace firing	26·0
(*b*) Boiler coal for process work	16·5
(*c*) Boiler coal for space heating	12·5
(*d*) Electric power for miscellaneous plant	12·4
(*e*) Electric power for casting	11·7
(*f*) Electric power for rolling	6·4
(*g*) Town gas	5·5
(*h*) Electric power for annealing	5·0
(*i*) Fuel oil and creosote/pitch	4·0
	100·0

The smallest works could quickly and accurately make an analysis of this kind and provided with such figures can begin to examine where potential savings can be made.

The answers to the problems with which we are faced fall into two broad classes :—

(1) Good housekeeping.

(2) Long-range work which may involve re-design of furnaces, revision of furnace-operating technique or change of process.

Ordinary commercial prudence dictates constant vigilance in watching for savings, and in works of any size, a whole-time official of some seniority will probably be found to be justified.

In tackling the second class of problem it is not easy to obtain new plant at present, but I hope that the Government Departments concerned will do all they can to help the industry to modernise its equipment. Very little furnace equipment supplied before the war comes up to the ideal or indeed up to the standards now attainable. The installation of electric furnace equipment, for instance, has made great progress in the past ten or fifteen years and its use has set a high standard of efficiency. On the other hand, electric power is so easily obtainable that it is all too readily wasted.

In the use of electric power suitable arrangements must be made for check metering, individually, all units of power consumption. Properly collated figures should be kept of production in relation to power used, so that prompt action may be taken when necessary. The fact must be borne in mind, and drummed in constantly to all those who operate electric plant, that for every unit of electricity consumed, four times its thermal value is lost in its conversion from coal. No form of energy is so easily wasted as electricity, for without check by close instrumentation, serious losses can and indeed do occur without any one being the wiser.

This brings me back to the point at which I started—the paramount need for instruments, records and statistics, which must be *used*—and not merely kept to salve the consciences of managers—to help them and the operatives to maintain continued and effective fuel economy.

The Institute of Metals and the industry it serves are fully alive to the need for fuel conservation and have already done much in this direction. That we are not content, still less complacent, can be gathered from the tenor of my remarks.

I have emphasised the importance of a scientific approach to the problems even by the smallest industrial units and perhaps I may therefore be excused if I urge the same approach on the part of the Ministry and those acting on its behalf. I would particularly suggest that the possibilities of the increased use of oil firing should be explored. Many metallurgical processes are specially suited on technical grounds to oil firing, often in spite of increased prime costs. Such quantities of oil as we can afford to import could be put to no more effective use than in these operations.

It would seem that the time has come when cuts of fuel should be more scientifically made than by a simple overall percentage. Present arrangements tend to favour those users who have been, or still are, using fuel wastefully, rather than those who have perhaps for years maintained a high standard by scientifically applied study and action. I feel sure the Minister and his officers are fully alive to this point, but a much more general application of the principle now advocated would give encouragement to the efficient and spur laggards into action.

Mr. Geoffrey Marchand (President, Society of Glass Technology) : To us, fuel is a vital raw material. Without it we cannot begin to make glass, and, having regard to its size the glass industry is relatively one of the most important consumers of fuel. Not only do we need assured supplies of the appropriate fuels at an economic cost, but we must have them in the right time and place, and of the right quality, and the acute fuel position is therefore a matter of grave significance to us, so that we are keenly alive to the need for fuel economy.

Because of this, the Society of Glass Technology has always taken a live interest in every aspect of the utilisation of fuel, and as Dr. Halle brings out in his admirable paper, the very first volume of the Journal of the Society contained two papers on the heating and design of glass furnaces. That was nearly thirty years ago, and since then a long series of papers on fuel and furnace problems has been regularly published in our Transactions. Some twenty years ago the Society established its Furnace Committee, which has actively pursued questions of furnace operation, design and efficiency. This committee is composed of glass manufacturers and furnace builders.

In the early part of the war, in conjunction with the Glass Delegacy of Sheffield University, there was established a sub-committee known as the Fuel Efficiency Committee of the Glass Industry, whose duty has been to encourage fuel economy within the industry by every possible means. The work of this committee has included the establishment of a panel of lecturers for every glassmaking centre in the country, the training of operators of boilers, producers and furnaces, the publication of a " Fuel Efficiency Supplement ", the regular issue of questionnaires to every glassmaking firm for the assessment of standards of fuel and furnace efficiency, the preparation for the book " The Efficient Use of Fuel " issued by the Fuel Efficiency Committee of the Ministry of Fuel and Power of a chapter on furnace control in our industry, and many other activities. The glass industry can claim a good record in fuel efficiency although there is still room for substantial improvement.

Normally, of course, coal is our principal fuel, although as Dr. Halle's paper points out, we also use both liquid and gaseous fuels. Speaking very generally, in 1938 the industry used approximately 900,000 tons of coal. As so substantial a user of coal we have, not unnaturally, been one of the first targets of the Minister of Fuel and Power in his efforts to save coal, and we have recently agreed with his Ministry to begin to convert wherever possible, from coal to fuel oil, and we have undertaken to do this as much in the national interest as in our own.

The speaker concluded by commending Dr. Halle's paper (page 46) and said that the statements made in it were supported by practically the whole of the British glass industry.

1. Problems in Fuel Efficiency

By C. HULSE, B.SC., and R. J. SARJANT, O.B.E., D.SC.*

INTRODUCTION

The objects of this paper are to review the present position of some of the problems relating to the efficient use of fuel in the iron and steel industry, and to indicate possible solutions and lines of approach for future developments.

The problems discussed relate to works where processes may be somewhat specialised and where there has been in the past a free selection of the most suitable fuel for a specific purpose, according to its availability and economy of utilisation. They do not necessarily apply to works of the fully integrated type, where the sole use of coal is limited to the coke ovens, and where the secondary needs for heat and power are satisfied by the available supplies of by-product (blast-furnace and coke-oven) gases.

For the purposes of this presentation, the problems may be classified as follows : (i) Those dealing essentially with the fuel and the means taken for its efficient combustion ; (ii) those relating to plant design and the mode of heat transference to the medium being heated ; (iii) those mainly associated either with organisation or with technique. In this last section special prominence is given to the need for plant surveys with suitable instruments and for the necessary organisation and education to ensure the application of existing knowledge among the many, rather than to rely on spectacular advances by a few. Finally, some of the wider problems of research involved are briefly considered from the angle of suggestion.

THE BEARING OF FUEL SELECTION ON EFFICIENCY

Much controversy has raged round the question of the price structures of fuel for different purposes ; this problem stands out as a national one and demands the earliest possible attention. Availability of any type of fuel is mainly a local question, and little can be done in the present circumstances of restricted supply to obtain the ideal fuel for a specific purpose. Many works had, during the years before the war, worked out their own salvation in this respect, but war conditions have since interrupted such selection to a considerable extent. The works with which the authors are associated had for many years utilised a method of evaluating coals for industrial uses on a thermal basis, in which the ascertained calorific value on a basis of unit cost was adjusted for various operational factors ; the result was that an " industrial value " of the fuel was determined. In the case of coal these factors had reference to ash content, clinkering characteristics of ash, and swelling character, while in the case of coke much importance was attached to the significance of the drop test, which had been found to give the best criterion of a hot-melting coke for cupola practice. In recent years, however, the problem has been to apply a much wider range of fuels (usually of an inferior character) to uses to which a particular selected fuel had previously been applied. How far it is desirable in the national interest and on technical grounds to revert to a free selection of suitable fuel is one which might well be given consideration.

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* Paper presented to the Iron & Steel Institute, 1947.

COAL

Coal is still the cheapest available source of heat for industrial purposes, and probably will remain so for many years to come. In furnace practice, however, the cost of the heat unit must be considered, not at the point at which the fuel is burned, but where it enters the material being heated. In this respect the questions of thermal efficiency, ease of control, labour, maintenance and transport of fuel and ash require to be considered. When these factors are taken into account the pre-eminent position of raw coal becomes seriously challenged by gaseous fuels and even, in some cases, by electricity. These challenges become all the more real when the questions of quality of heating and of convenience of operation are considered.

In certain cases (e.g., a furnace used only at infrequent intervals) economic considerations may actually favour the continuance of a wasteful method of firing on the grounds that further capital expenditure is unjustified ; even where the situation would warrant replacement by a more modern unit other factors might delay the changeover. The cautious industrialist cannot be blamed in these days if he elects to continue with the use of a fuel of which he has been receiving reasonably regular supplies, rather than tie up his capital in plant requiring a grade of fuel which might later prove difficult or impossible to obtain. Such conditions have favoured the retention of the practice of hand firing on grates.

Hand Firing on Grates.—The greatest disadvantage of this type of firing, compared with other means, lies in the lack of control over combustion. At a given rate of input of primary air the secondary-air requirements vary continuously during each firing period, resulting in wide variations in the composition of the furnace atmosphere. This is not only wasteful in fuel but, in certain types of operations (particularly at high temperatures or if the sulphur content of the coal is high), the variations may lead to heavy scaling of the charge. As has been shown by various workers,[1, 2, 3] the degree of scaling increases rapidly with increasing oxygen content of the furnace gases, and considerable scaling may be produced by sulphur dioxide, even in reducing atmospheres.

A further complication with which the operator of a hand-fired furnace has to contend is that as the furnace temperature rises the draught at the stack increases. This applies equally to all types of natural-draught furnaces, but when this variable is added to the cyclic variations of each firing period, the task of maintaining constant combustion conditions becomes well-nigh impracticable for modern standards of heating requirements. By proper attention to the design of the combustion chamber and by using one of the proved methods of firing (combined with good firing technique) it is possible to achieve a certain degree of uniformity, but even under the best conditions quite serious variations may occur.

An illustration of the type of result which may be expected when conditions are not of the best is given in Fig. 1. This shows the variations in composition of the furnace gases observed throughout two firing periods during the heating from cold of a batch-type heat-treatment furnace. The first set of curves relate to a period during the initial stages of the heat when the furnace and charge were still relatively cold, and the second to a period when the furnace was nearly up to temperature. It will be seen that wide variations occur in both cases, the conditions ranging from strongly reducing to strongly oxidising. Thus, the extreme values recorded in the first set of curves were, on the one hand, nearly 10 per cent. of CO and, on the other hand, 9 per cent. of O_2, the latter corresponding to about 76 per cent. excess air. Comparison of the two sets of curves reveals that the point in the cycle corresponding to 25 min. after firing in period 1 is reached in the case of the second period in only 4 min., and that the rate of increase in the excess air is much more rapid in the second case. As the rate of supply of primary air was similar in the two cases (if anything being slightly less in the second) it is apparent that, apart from any slight differences in the conditions of the fuel bed, in period 2 the duration of the evolution of the volatile matter was much shorter, owing to the higher temperature of the firebox and furnace generally, and the amount of secondary air drawn into the furnace was much greater, also because of the higher temperature of the furnace system.

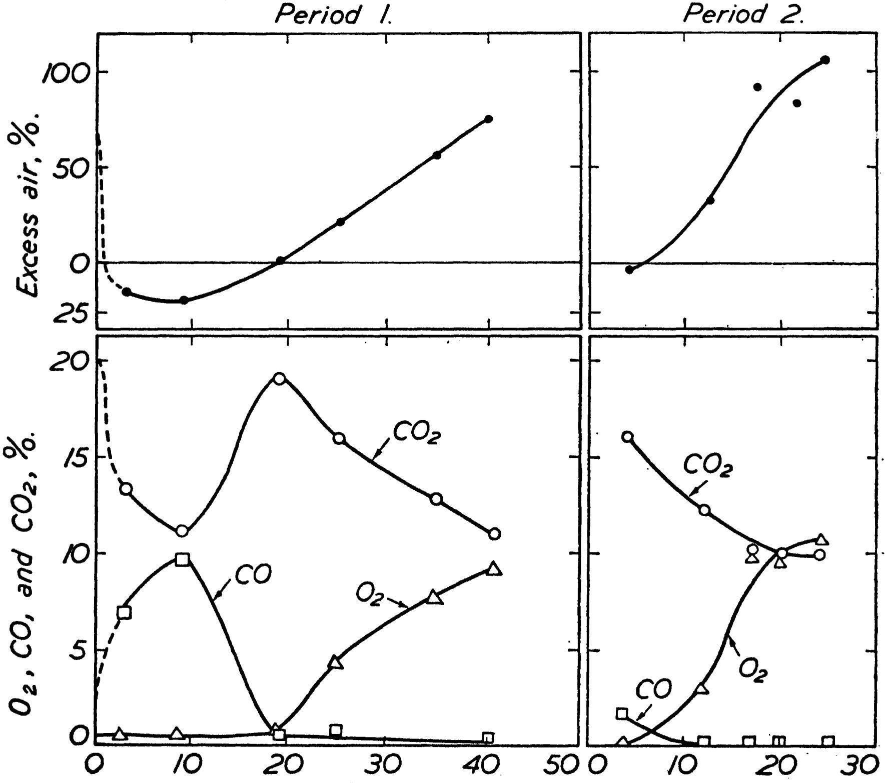

FIG. 1.—Variations in Composition of Furnace Atmosphere of Hand-fired Furnace. (Periods 1 and 2 relate respectively to firing periods during the early and later stages of heating up from cold.)

Firebar Design.—As it would appear that hand firing must remain as a practical technique for some time yet, the problem of grate design, particularly of the bars, still remains ; the authors consider that finality has not yet been reached in this question. Little is known of the laws governing the conditions of flow inside a bed of burning coal, and present grate designs are largely based on trial and error. In the case of one particular design and for the same type of coal it was found that an expression of the type :

$$P = cF^n$$

where P = pressure drop (in. w.g.),
F = air flow (cu. ft./min./sq. ft. of grate area),
and n and c are constants,

gave a partial correlation. When P and F were plotted logarithmically all the points fell on a band which gave a value for n of approximately 1·45, the position in the band being apparently dependent upon the time after firing. There would seem to be a case for further work along these lines, including additional factors, such as the type and size of coal and the depth of the bed.

Mechanical Stoking.—Most of the disadvantages associated with the firing of raw coal are mitigated by the use of mechanical stoking. As the fuel is fed continuously into the combustion chamber, the primary and secondary air are both capable of correct adjustment and may be made to follow variations in the rate of fuel feed as governed by the load requirements. The readiness with which mechanical stoking appliances may be adapted to automatic control is a further point in their favour.

Typical combustion conditions which were obtained during tests at two similar rolling-mill reheating furnaces, one fitted with an underfeed-type mechanical stoker and the other hand fired, are contrasted in Tables I and II.

TABLE I

COMBUSTION CONDITIONS IN STOKER-FIRED FURNACE

Furnace conditions	Furnace atmosphere				
	Composition, per cent.			Air	Volatile unburnt combustibles, per cent.
	CO_2	O_2	CO		
Heating up cold charge ; smoky flame.	18·3	0·8	0·1	Negligible excess.	0·4
Heating up cold charge ; flame more smoky.	18·1	0·3	1·5	Slight deficiency.	5·1
Soaking heat ; slightly smoky flame.	18·3	0·7	0·6	Negligible excess.	2·1

TABLE II

COMBUSTION CONDITIONS IN HAND-FIRED FURNACE

Furnace conditions	Air
Average ; immediately after firing	Deficiency to 20 per cent. excess.
After raking fires during period when flame was coming over the bridge .	60–80 per cent. excess.
During periods when the fire had burned down and the furnace chamber was clear.	100–150 per cent. excess.

The bearing of such differences as those illustrated above on the question of fuel economy, as well as on that of loss of steel due to scaling, will be readily appreciated. Nevertheless, in spite of the advantages shown in these tables to be possessed by mechanical firing, and keeping in mind the other obvious superiorities of this system, there is still considerable room for improvement both in the design and the performance of mechanical-firing appliances. The demands made by metallurgical furnaces are much more stringent than those encountered in boiler practice, in which field the technique of mechanical stoking found its first ready success. Considerable flexibility is required, and sometimes load conditions may render desirable the reduction of the rate of fuel feed below that at which burning-back of the fuel or damage to mechanical parts, due to radiation from the combustion-chamber refractories, may take place. Another point in this connection is that combustion-chamber temperatures are necessarily higher in furnace practice than in boiler practice for the same size of stoker. In such cases the costs, either of fuel or of maintenance are bound to be higher than is desirable.

In many existing installations economy could probably be effected by attention to points of detail. This was exemplified in a recent test of the rolling-mill furnace already mentioned in connection with Table I, in which it was found that, although at suitable rates of output a fuel consumption of less than 2 cwt. per ton of product was attained, the degree to which the rate of fuel feed could be varied was insufficient to meet all types of demand. In actual fact only three rates of fuel input were possible, amounting to 35, 60, and 100 per cent. of the full load. In such cases as this considerable savings may be achieved by small mechanical modifications of the controls to give greater flexibility, and by ensuring that the air-valve settings corresponding to the different rates of fuel feed are clearly marked, and properly set.

PULVERISED FUEL

Up to the commencement of the war great strides had been made in the use of pulverised coal for furnace firing. The modern remote-control bin-and-feeder system and unit pulverisers are both capable of giving a degree of flexibility of control which approaches that attainable by the use of gaseous fuels, and the more recent designs of pulverising equipment have achieved a standard of reliability in providing a product of uniform fineness adequate for most furnace purposes. As with gaseous fuels the burners may be disposed in a manner designed to give as rapid a rate of heating as is consistent with the limitations imposed by the nature of the material to be heated, and to assist in the ready attainment of temperature uniformity.

On the other hand, pulverised-fuel installations necessitate both careful design and subsequent rigid control if the troubles associated with their use are to be avoided. The worst of these troubles is probably that of fluctuations in the rate of fuel feed. These may be due to irregularities in the pipe-lines or to too high a moisture content in the coal, and may lead to actual blockage. For this reason it is essential that the moisture content of the coal going to the pulverisers should be kept below a very low upper limit, and it may be necessary to instal some form of coal dryer. High rates of output and efficiency are obtainable even with coals of high ash content ; indeed, the use of pulverised coal as a boiler fuel was originally adopted partly with a view to the utilisation of low-grade fuels. The marked progress in American pulverised-fuel practice can be ascribed to the existence of a relatively high ash content in many

American coals. In furnace practice it is usually desirable to keep the ash content as low as possible as, even with moderate ash contents, flue deposits build up all too quickly, and it is inevitable that finely divided coal ash should become a strong fluxing agent on brickwork, particularly at high temperatures. The authors have experienced cases in which the ash from powdered coal has been sintered solid in the off-take flues owing to irregular combustion conditions arising from choking of the feed mains and the resulting fluctuations in the rate of coal feed. It is owing to the fine ash carried over by the waste gases that waste-heat recovery is not generally practised in conjunction with powdered-coal firing, and the practical difficulties to be overcome in this connection are most formidable. A further problem in connection with this method of firing, particularly in the case of large installations, is that of atmospheric pollution from the emission of grit, the prevention of which demands auxiliary grit-arresting plant.

COKE

Were it not for the fact that the price per therm compares so unfavourably with that of coal, the use of coke for furnace heating would be even more widespread than is the case at present. As coke consists essentially of carbon (together with impurities in the form of ash) the disabilities associated with the cyclic variations in the secondary-air requirements in the case of coal do not apply. Provided that the grates are maintained in good condition and a firing system is adopted which will maintain a uniform fire, good control of combustion conditions and of the composition of the furnace atmosphere is practicable.

Coke is widely used in foundry practice of all kinds, though even in this application it is today being replaced to some extent by gaseous fuels. For many years it has found a ready application in built-in producers (by means of which the sensible heat in the producer gas may be utilised) and in suction units used primarily for power production by means of gas engines. More recently, however, there has been a marked trend for the submission of coke to gasification in centrally situated units. These units are usually associated with a wet-cleaning plant, and the cleaned gas is boosted to a pressure of about 2 lb./sq. in. for distribution.

GASEOUS FUELS

Clean gaseous fuels are almost ideal in respect of ease of control of combustion, the degree to which the type and nature of the flame may be varied, and the readiness with which they lend themselves to automatic control. These and other features, together with the fact that burners of suitable type may be placed in such positions with respect to the charge as will enable rapid and uniform heating to be obtained, give the furnace designer greater scope in the matter of mechanisation, waste-heat recovery, and the use of special designs to suit particular requirements. It is significant that most (if not all) of the more fundamental changes in furnace design which have taken place in recent years have been associated with the use of gaseous fuels or of electricity.

By means of equipment of a special type utilising the principle of surface combustion, exceedingly high rates of heat release may be obtained and there would seem to be scope in this country for the more extensive use of this form of heating, which in America is now finding increasing application, with almost phenomenal results.

In regard to rates of heating in furnaces, experience with the type of burner mentioned has shown that much higher rates of heating are practicable with metals than had hitherto been thought to be the case. This has been shown also by a recent paper,[4] in which it was demonstrated that the practicable rates of heating of steel (in so far as no disturbing metallurgical requirement may limit those rates) are higher than had been realised, provided that the heating is uniform on all sides of the material being heated ; this last circumstance determines in many cases the heating times required. In practice it would appear that the principal factor governing the soaking time required to attain temperature uniformity is the limitation imposed by the furnace, and particularly by a cold hearth, and not the thermal characteristics of the material being heated. In so far as progress may be made towards overcoming the disabilities indicated, the use of either gas or electricity, preferably in combination with mechanisms which may move the charge, would appear to be necessary.

A modern means of attaining better uniformity of temperature in a furnace chamber is the use of the so-called diffusion burner, in which the gas and air are projected into the furnace in a number of parallel streams which slowly diffuse and give a long flame. Another method of obtaining slow admixture of gas and air was applied in the Chantraine furnace ; this type of furnace has been in use for many years. In this case the gas is admitted to the furnace chamber either through a port at the end of the furnace or at a number of points along its length, at a level just above the hearth ; the object of the latter modification is to reduce the incidence of scaling by the provision of a rich gas in proximity to the charge. The air is admitted through a series of ports in a false crown. Success in attaining the objects sought has been claimed both for the diffusion burner and the Chantraine furnace.

Fundamental research into the combustion of inflammable gases in both aerated and non-aerated burners has been undertaken by Professor D. T. A. Townend and his colleagues at Leeds University. The work so far published[5, 6] has been concerned with the measurement of flame velocity and the mechanism of the phenomena of light-back and blow-off. In light-back the gas velocity at points nearest the periphery of the burner throat and the character of the dead space would appear to be of importance. In aerated flames the tendency for the flame to blow off decreases as the burner diameter increases, and double-cone flames are progressively more stable as the proportion of the gas in the mixture is increased. The publication of the results of further work along these lines, which work should be capable of putting burner design on a scientific footing, will be awaited with interest.

The national position with regard to coking coals gives one furiously to think how the problem may be approached from the standpoint of the industrial user of gaseous fuel in the future. Undoubtedly the gas industry may be able to help by extending the range of coals which may be economically gasified in retorts ; also it may be necessary to practise total gasification on a larger scale than at present. In this connection the question of water supply for cleaning the gas and for the subsequent removal of undesirable impurities from the effluent offers a problem of some magnitude ; the alternative use of electrostatic cleaning provides a promising future line of approach to this question. A further distribution problem is associated with the high pressures and the large-diameter pipes required to distribute gases of low calorific value. In certain circumstances, depending largely on economic considerations relating to the size of the units, it may be necessary to locate the production unit adjacent to the works. On the other hand, the case may be cited[7] of the use of Mond gas in South Staffordshire where gas of a calorific value of 160 B.Th.U./cu. ft. is supplied at a distribution pressure of 7 lb./sq. in. to works scattered over an area of approximately 100 sq. miles ; this system has now been operating for many years.

Coke Producer Gas.—Mention has already been made of coke producer gas ; in specific uses this forms a practicable substitute for town gas, over which it has some advantage in the heating of metals in respect of its low flame intensity. The following information relates to the cleaning and purification of coke producer gas in the case of two recently installed plants with a total capacity of approximately 1 million cu. ft./hr. The cleaned gas was distributed in mains which formerly carried town gas ; it was necessary, therefore, to ensure that no possibility of choking could arise. To this end oxide scrubbers were used, of which the main function was that of a filter rather than a de-sulphurising unit. It was found in practice that, as well as providing a gas of which the dust content was less than 1 grain/100 cu. ft., the wet-cleaning system and oxide boxes reduced the sulphur content of the gas from a range of 85–105 to a range of 20–60 grains/100 cu. ft. Thirty per cent. of the sulphur removal was accomplished in the washery, where soda ash was used in a closed circulating system with settling tanks, and 25 per cent. in the relatively small oxide boxes. After three years of working, the only corrosion trouble experienced in the whole unit, from producers to boosters, has been in the elbow at the point of entry of the downtake carrying the hot raw gas to the cooling tower. This freedom from corrosion is ascribed to the addition of soda ash to the circulating wash-water, the pH value being kept at about 7·5. The point at which corrosion took place was conducive to the formation of an almost stagnant film of water containing a relatively high concentration of sulphur dioxide, absorbed from the gas.

A second plant was of similar type, but in this case the bulk of the sulphur was required to be removed. Accordingly larger oxide boxes were installed. A system of rotation of the order in which the gas passed through the boxes was used in which partial revivification of the oxide could take place *in situ.* As a result a high standard was attained, both of de-sulphurisation and of the duration of the period before it became necessary to change the oxide in the boxes.

A considerable amount of investigation has been undertaken in connection with these units with regard to the question of sulphur balance. Various methods of sulphur determination have been employed, ranging from the use of the gas referees' apparatus to absorption in solutions of cadmium chloride, silver nitrate or bromine, followed by volumetric or gravimetric analysis, but finality has not yet been reached on this question. The bulk of the sulphur in the gas is undoubtedly in the form of hydrogen sulphide ; varying amounts of sulphur dioxide have also been observed, from a trace to about 15 grains/100 cu. ft. of gas obtained from cokes containing 1–1·5 per cent. of sulphur. An appreciation of the conditions in the producer which determine the proportion of sulphur dioxide present in the gas is of importance when considered in the light of the extremely corrosive nature of this constituent in the presence of moisture ; this consideration necessitates suitable steps being taken to protect the various units in the cleaning and distributing systems. In this field there is need for further investigation.

The results of a study of the effect on gas quality of variations in the proportion of steam in the blast supplied to the producers are of interest. A comparatively large number of determinations of the calorific value of the gas were made at different blast saturation temperatures by means of a Boys calorimeter ; an analysis of the values obtained is illustrated in Fig. 2. It has long been known that over the range of values normally employed the calorific value of producer gas tends to fall as the blast saturation temperature is increased, but the occurrence of an optimum value (such as may be seen in Fig. 2) would appear to have escaped previous comment. It is thought that the cause of the decrease in calorific value as the saturation temperature is lowered below 57° C. may be due to the formation of clinker interfering with the uniform working of the producers.

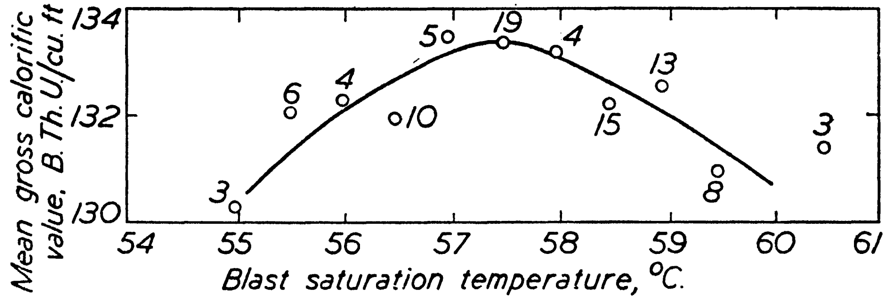

FIG. 2.—Variation in Calorific Value of Coke Producer Gas with Blast Saturation Temperature. (The figures beside each point indicate the number of observations available for computation of the mean calorific values corresponding to the various temperatures.)

With regard to the working temperatures attainable by the use of coke producer gas, these naturally depend on the degree of preheat employed in the case of both the gas and the air. Temperatures of well over 1200° C. could be readily obtained by using the raw gas at a temperature of approximately 250° C. with air preheated to 350° C. When cold, cleaned gas was used, with air again at a temperature of 350° C., in a furnace which had been originally designed to burn town gas, a temperature of only 1125° C. was practicable with burners giving a good standard of flame admixture, but no special degree of intensity of air/gas mixing. No difficulty has been experienced in attaining temperatures of up to 1200° C. when using the cold gas in a furnace equipped with regenerators for preheating the air.

Although the highly toxic nature of carbon monoxide gas is well known to those familiar with blast-furnace practice, it may happen that gas plants of this type might be installed in works where the operatives are unaccustomed to it. In such cases, particularly where high pressures are employed, special safety precautions and frequent testing for leakages are necessary. The palladium chloride technique[8] for the estimation of carbon monoxide concentration has been found to be useful in this respect.

LIQUID FUELS

Liquid fuels combine some of the advantages of gaseous fuels with a number of the disadvantages of coal and coke. Burner design has reached a stage whereby a sufficient degree of uniform atomisation may be obtained to ensure complete combustion without the use of excess air. By suitable placing of the stock in the furnace to avoid premature chilling of the flame, and by good maintenance of the burners and atomising equipment, no difficulty need be experienced owing to inefficient combustion. During the war years the shortage of petroleum fuel-oil has led to the development of a standard creosote/pitch mixture.[9]

Liquid fuels require the service of such ancillary plant as tanks, heaters, and pumps, and care is needed on the part of the furnace operator to ensure their efficient use. Minute attention to detail is required if the best results are to be obtained ; for example, when shutting down burners it is necessary to protect them from radiation from the furnace chamber, as such radiation may cause the formation of a coke-like product able to choke the burner. Nevertheless, in situations where a suitable gas supply is not available, the need for the use of liquid fuel is likely to increase. If future developments in the treatment of coal, made with the object of obtaining an increase of the chemical products, should be successful, there will always be scope in the field being discussed for the use of by-product fuel-oil.

A further specialised application of liquid fuel is that of tar injection to low-grade gases (e.g. in the open-hearth furnace) but controversy seems to range round the economic advantages of this measure. The problem is not likely to arise in works of the type the practice of which is discussed in this paper until an economical means has been developed of de-sulphurising and de-tarring bituminous-coal producer gas.

DEVELOPMENTS IN FURNACE DESIGN AND CONSTRUCTION

The principal developments under this heading fall into the following classes :—

(I) General mechanisation of furnace operation.

(II) Improvements in instruments and automatic control.

(III) The use of waste heat ; recuperation ; reduction of storage losses by the use of hot face insulation, and by the use of porous brick linings.

(IV) The use of forced circulation of the furnace gases.

(I) MECHANISATION

General mechanisation has extended to the use of moving hearths, either in annular rotary furnaces or in continuous-bogie-type furnaces. The main advantage of the former type has been the value of a hot hearth in ensuring quick heating, and temperature uniformity in reheating. Where the material is of too massive a type to permit of the direct transfer of the cold charge to the hot rotary hearth, a continuous solid-hearth preheating furnace has been used. The use of the continuous-bogie furnace has enabled relatively heavy charges to be carried through continuous furnaces, both for reheating and heat treatment. Conveyor furnaces of a multitude of types continue to be developed —pushers, rollers, walking beam (for sheet annealing), and rotating cylinders (for small parts). Economy arises through the saving of labour, the increase of output, and a much higher standard of uniformity of heating.

For reheating billets for piercing operations, gas-fired rotary-hearth furnaces utilising both town gas and coke producer gas and fitted with metallic recuperators, air/gas ratio control, and radiation-pyrometer control at the start and finish of the soaking zone, have eliminated a considerable degree of machining of the resultant forging ; at the same time, the higher standard of temperature uniformity attained has resulted in an improvement in the accuracy of piercing.

Walking-beam furnaces have permitted considerable advancement in the standard of treatment of sheets, and the use of compartment furnaces with push-through bogies and forced gas circulation has resulted in a considerable increase in output from heat-treatment furnaces.

The " top-hat " furnace, with tubular elements carrying the heating gases, has been applied to sheet and wire treatment in which controlled atmospheres are used. This type of furnace is, in a sense, mechanical in that a chamber cover may be moved from one batch of charge to another, after a treatment involving a required cycle of temperature change has been carried out.

There has been a considerable development of mechanical furnace-auxiliary devices of all kinds. Some typical examples are :—

(*a*) In gas burners ; air/gas ratio control, combined with draught control, operated from a master controller governed by the furnace temperature. This would appear to be the ideal combination of mechanical controls to ensure perfect combustion and an ideal rate of heat input, the two major requirements in control requisite for economical working.

(*b*) In charging and discharging machines ; an advanced standard of mechanisation has been reached in the former in regard to ease of control and size, and in the latter with respect to rapidity of quenching and removal from the quenching bath after the required period of immersion.

(*c*) In dampers and hearths ; jointed heat-resisting metal bricks or plates to overcome distortion and cracking.

The problems of mechanisation are bound up with two major lines of scientific progress (i) those fundamental advances in engineering science which are applicable to furnace practice, and (ii) the properties of the materials used in the construction of mechanisms, more particularly those involving the effect of high temperatures. The former depends upon external agencies and general progress in mechanical engineering science ; it contains no specific problems which are not also of much wider interest. The latter involves certain critical properties peculiar to the conditions of furnace practice, such as resistance to creep, the effect of expansion in repeated heating and cooling, and resistance to the chemical effect of furnace atmospheres, in all of which research is continually being pursued by the interested organisations.

(II) IMPROVEMENTS IN INSTRUMENTS AND AUTOMATIC CONTROL

The contributions of physical science to engineering practice during the past decade have been outstanding. In the development of instruments for the more efficient use of fuel, electrical mechanisms, enriched by the use of the amplifying valve and the photoelectric cell, play a part of rapidly growing importance. In the next few years it is probable that electronic devices of many types will become available for use in instruments which are likely to be suitable for furnace practice. The ideal to be aimed at is the automatic furnace, but there are many limitations to be placed upon the attainment of this goal ; some of these limitations are purely sociological in character. Thus it has often been urged that the search after merely push-button control may eliminate from a process that exercise of human intelligence and keen-eyed curiosity on the part of the operative which is desirable in any industrial operation. High-temperature processes require in their application methods which are simple and absolutely reliable (at present possibly over-sanguine demands), but it remains in such cases a desirable aim that automatic mechanisms should be reduced to the simplest terms. Naturally the number of instruments required and their function must be related to the size and economic importance of the heating unit. The efficient performance of an open-hearth furnace, the re-heating plant feeding a large continuous mill, or a large battery of boilers may well merit a well-equipped instrument panel which cannot be justified in the case of smaller units.

In general, one master controller should be sought and this should be regarded as an integral part of the furnace unit. The experience drawn upon in this paper in regard to the use of instruments would suggest that there should be :—

(*a*) An autographic record of the critical control-feature. (Perhaps the best example of this is in an allied industry—a cement kiln, in which the oxygen content of the exhaust gases from the kiln is recorded.) In the heavy industries generally the critical feature may be temperature, or rate of fuel input. In open-hearth furnaces new and important developments are the roof pyrometer and the immersion thermocouple.

(*b*) Means to observe or control the air/gas ratio or flow.

(*c*) Means to maintain balanced draught. A sensitive draught gauge before the outlet damper is always worth while.

Simple, robust, and readily accessible instruments are as important as the furnace itself and no furnace which does not operate purely on a push button should be without its proper complement of these accessories.

Further, a branch of the subject which could profitably merit attention is the development of a relatively simple mechanism—sufficiently robust for workshop conditions—for automatically controlling draught. There is probably no greater source of heat losses in industry than the improper draughting of furnace plant. Surveys of the composition of the furnace atmosphere at different levels and locations will often reveal unexpected results which the unaided skill of the operator may well fail to detect.

As a pointer to the significance of air inleakage, a difference of from 200° to 400° C. has been observed to have occurred in the temperature just above a bogie hearth following a tightening-up of the efficiency of the sand seals and the elimination of door leakage.

(III) WASTE-HEAT UTILISATION

The utilisation of waste heat is frequently in the main an economic rather than a technical problem. This applies particularly in the case of the waste-heat boiler in which problems of design and efficiency have received considerable attention in the past, and the elements determining the output of steam from the plant can be readily ascertained. In general, technical opinion favours the use of the fire-tube boiler for a number of reasons which include the facts that the fire tube is easier to clean, and that the handling of large volumes of exhaust furnace gas at relatively low temperatures involves heavy draughting conditions apt to give rise to air inleakage if suitable provision for its prevention is not incorporated in the boiler design. If this latter limitation is taken care of and provided that proper provision for the cleaning of the tubes is made, there seems to be no reason why a water-tube boiler should not also be satisfactory. There are distinct advantages in the use of the higher steam pressures to be obtained, provided of course that a use for the steam can be found and that the temperature and weight of the gases permit an economical rate of evaporation to be attained. The problem is one on which further enquiry may not be unprofitable for those who are looking for new developments in this branch of waste-heat recovery. Alternatively, can it be said that a state of apparent finality has been reached in the design of the waste-heat boiler ?

TABLE III

AIR PREHEATING : CHARACTERISTICS OF FUELS

Fuel and heating value	Air required for combustion of 1 lb. of fuel		Volume required for release of 1,000 B.Th.U.		B.Th.U./ cu. ft. of products.	Sensible heat, per cent. of gross heat		Potential heat available for heat recovery in cooling of gases from 1200° to 600° C., per cent.	Relative index of air preheat obtainable. Col. $\frac{(4)\times(8)}{(3)}$
	Lb.	Cu. ft. (at 60° F.)	Air, cu. ft.	Waste gases, cu. ft.		1200° C.	600° C.		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Coal 14,500 B.Th.U./lb. . .	10·1	132	11·0	11·7	86	48·3	21·7	26·6	27
Coal 12,750 B.Th.U./lb. . .	7·1	116	11·0	11·9	84	49·3	21·5	27·8	30
Fuel oil	14·0	184	9·85	10·4	96	46·8	21·5	25·3	27
	Air vol./gas vol.								
Coke-oven gas (475 B.Th.U./cu. ft.)	4·06		8·55	10·0	100	48·1	20·9	27·2	32
Producer gas (163 B.Th.U./cu. ft.)	1·28		7·85	12·7	79	65·6	29·8	35·8	58
Blast-furnace gas (92 B.Th.U./cu. ft.)	0·69		7·50	16·7	60	79·1	34·2	44·9	100

Recuperation.—The advent of heat-resisting metals into engineering practice has resulted in the establishment of the metal recuperator. The greater compactness of the unit, its accessibility, ease of repair, and the absence of leakage in a proper design, make it much superior in furnace practice to the older type built of refractory material. The metal recuperator may be placed on the crown of the furnace as well as in the flues, and higher velocities of the heat-exchanging gases may be carried, with a resultant increase of the overall heat-transfer coefficient and better utilisation of available heating surface. Further, recuperator tubes may be incorporated in flues in the furnace walls so that the heat storage in the furnace structure may also be picked up in the preheated air and/or gas. A frequent problem in a recuperator is how to raise the value of the heat-transmission coefficient on the waste-gas side of the heat-exchanging wall. In a nest of metallic tubes this coefficient is normally low, because of the usually low velocities of the gases passing to the exhaust unless an induced-draught fan is employed. The importance of gas radiation in heating has only been appreciated in relatively recent years. Gas radiation may be picked up by additional refractory walls, which in turn re-radiate to the heat-exchanging surface of the recuperator. The proportion of heat radiated from the refractory surfaces from this source may amount to an additional 30 per cent. at 800° C., as compared with the small proportion transferred by convection.

The relative merits of preheating the air used in conjunction with different fuels is apparent from the data given in Table III. The percentage of the potential heat of the fuel which is available for heat recovery as the products of combustion are cooled from 1200° to 600° C. is shown in column (8) of that Table. In columns (3) and (4) are given the volumes of air and waste gases respectively which are involved in perfect combustion in order to release 1,000 B.Th.U. An approximate relative index of the air preheat obtainable for a given drop of temperature in the waste gases is provided in column (9), the index being obtained from the expression $\frac{\text{Col.}(4)}{\text{Col.}(3)} \times \text{Col. } (8)$. The results indicate the degree to which the lean gases are particularly good subjects for recuperator practice, and that, with good heat-recovery, they can be made thermally efficient in use.

A metallic recuperator applicable for waste-gas temperatures of up to 1000° C. or more and used in combination with an exhaust fan, is probably the most effective appliance of heat recovery in preheating practice. When operated in conjunction with a chimney, difficulties may arise ; a chimney is not a satisfactory controllable draught-engine (though its cost in capital outlay and of operation may appear attractive) and it does not reach its full efficiency until the maximum temperatures in the furnace are approached, whereupon the draught is generally required to be reduced.

Reduction of Storage Losses.—Progress has been made in the study of the heat storage in furnace structures and of the means to be taken for its reduction. Methods have been described,[10] utilising machine forms of calculation, for the determination of the heat storage, under conditions of variable flow of heat, for the typical conditions of intermittency experienced in normal practice. By these means the economical thicknesses of brickwork and of insulation can be established for conditions other than those encountered under steady conditions. The data in Table IV, apply to perfectly insulated firebrick walls, and show the relationship between the wall thickness and the time required to reach within a specified temperature interval short of the maximum attainable at full heat saturation of the wall. From these data it is apparent that the so-called " steady conditions " are rarely reached in practice and that any calculations of heat storage based on such conditions are only roughly approximate.

Unlagged walls of 9-in. firebrick and 4½-in. hot-face insulation, when subjected to cyclic variations of temperature (6 hr. heating, 6 hr. soaking, and 6 hr. cooling) showed that cycles of outer-face temperature could be repeated after a second cycle of temperature changes had been passed through, that is after the lapse of 36 hr.

Temperature–time curves relating to the external surfaces of firebrick walls and insulating refractories have been derived for different rates of heating of a type normally encountered in practice. Fig. 3, taken from the paper[10]

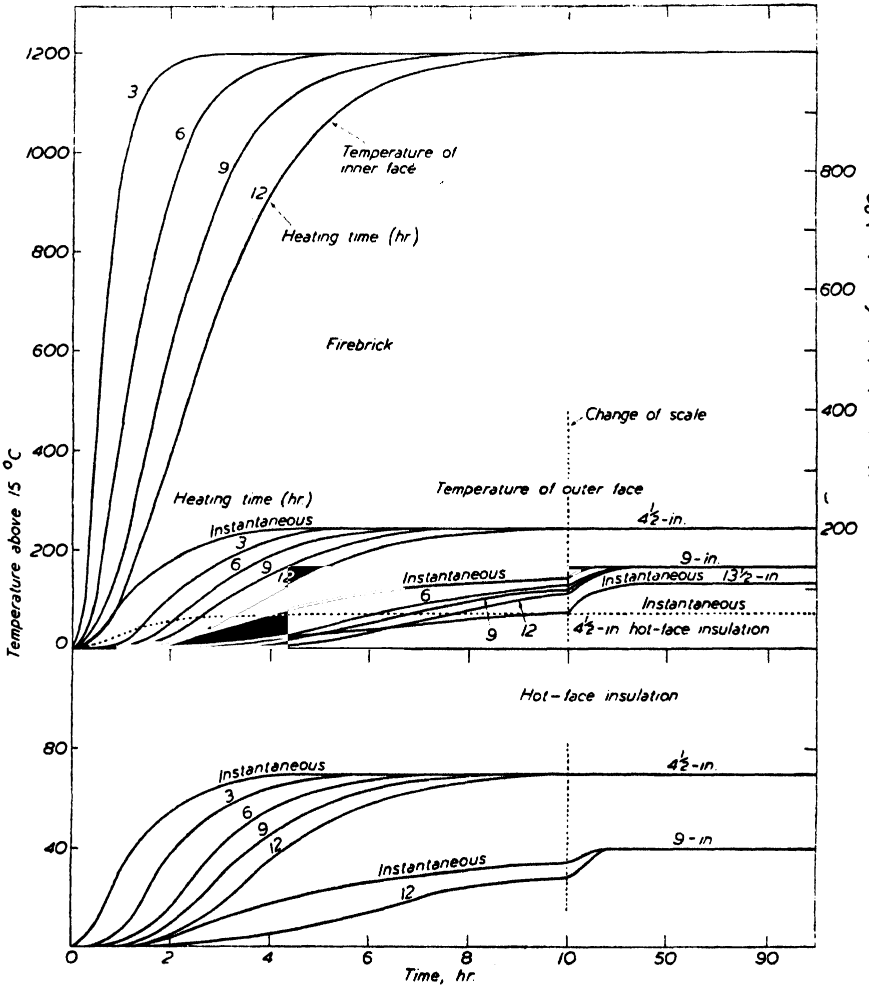

FIG. 3.—Temperature-Time Curves for External Surface of Various Types of Furnace Wall, Corresponding to Typical Heating Curves for the Inner Face.

already referred to (p. 197), illustrates an example of the technique. The data provide a general guide for establishing economy in intermittent practice of any particular type of wall. A point of fundamental importance is that developments of the machine methods of computation now in hand enable difficulties frequently associated with the existence of a thermal-diffusivity variable with temperature to be overcome, as well as permitting a detailed study of the behaviour of compound walls.

TABLE IV

TIME (HOURS) REQUIRED TO REACH WITHIN A SPECIFIED TEMPERATURE INTERVAL OF THE MAXIMUM FOR FULL HEAT SATURATION

Normal firebrick walls perfectly insulated

Temperature interval at firebrick insulation interface, ° C.	Wall thickness, in.		
	4½	9	13½
10	17	68	153
20	14	56	126
50	11½	46	103

Considerable investigation has been made into the properties of the refractories required to provide what has been termed " hot-face " insulation, that is to say, insulating firebricks of low heat capacity and possessing suitable chemical and physical properties to meet the requirements associated with the conditions within the working chamber of the furnace.

The mechanical properties essential are mainly a question of the behaviour of the brick in handling and transport. A cold crushing strength of 150 lb./sq. in. has been suggested as a tentative minimum.[10] The thermal advantage of the brick in reducing heat storage is approximately inversely proportional to its bulk density. In a furnace wall in practice, the temperature gradient across the wall is steep because of the highly insulating character of the brick, and the mean temperature is thereby reduced. Accordingly, for this reason, the brickwork as constructed could be expected to be capable of exerting a greater stability in service than might be expected from test data. The expectation of durability from this cause has been confirmed in panel tests. The usual problems of resistance to spalling, to slag and oxide fume, and to abrasion arise in this class of refractory to a greater degree than with dense refractories, so that there is a limit to the locations at which they may be used. Thus they are not usually suitable for hearths, door jambs, burner blocks, or bridge walls.

The Importance of Gas Permeability.—The importance of the gas permeability of the refractory structures used has been frequently overlooked in furnace construction. All furnace walls not specially protected are permeable to gas. If the difference in pressure between the furnace chamber and the external atmosphere is appreciable there is a tendency either for hot gas to flow outwards, or for an inleakage of cold air from the atmosphere ; both effects may result in a lowered thermal efficiency. A good diatomaceous insulating brick may have a permeability of well under 1 British unit (cu. ft./hr./sq. ft./ft. at 1 in. w.g.), but some of the porous insulating firebricks examined have been found to have surprisingly high permeabilities. In practice the permeability becomes reduced, owing to the effect of temperature on the viscosity of the gas. Ignoring the effect of temperature and possible changes in the brick on heating it is found that, for a case in which the porous brick has a permeability of 12·8 British units and a mean thermal conductivity of 1·68 B.Th.U./sq. ft./hr./° F./in., over the range of temperature involved, the heat loss for a 9-in. wall with a temperature gradient of 1000–80° C., and a pressure difference of 0·2 in. w.g. across the wall, is respectively 309 B.Th.U./sq. ft./hr. for non-permeable conditions and 427 B.Th.U. for outward permeable flow. The difference in the heat loss amounts to an increase, due to permeable flow, of 38 per cent. These facts point to the need for close joints and external plating and indicate the existence of a problem not yet solved by the makers of the porous bricks.

Fortunately these limitations are not universal, as entire walls and crowns of heat-treatment furnaces have been constructed with this type of refractory and are giving satisfactory operation. Normally, the hearth (for obvious reasons of durability) must be constructed of hard, dense refractories, but the question of insulation arises, as the zone of variable heat-soakage may extend to a depth of about 20 in.

Permeable Furnace Walls.—An interesting new construction in which the products of combustion are exhausted through the walls of the furnace, these walls being made of a permeable material, has been described by Anderson, Gunn, and Roberts[11]. The advantage of this construction over the orthodox design is that it results in the sensible heat of the waste products of combustion being used to supply the heat storage of the furnace wall. At the same time a more rapid attainment and a more even distribution of furnace temperature are practicable. The design has been incorporated in a variety of furnaces including bogie-hearth furnaces with hearth dimensions of up to 13 ft. 8 in. × 10 ft., wire patenting furnaces, natural-draught oven furnaces for carburising, and a relatively high-temperature furnace for special heat-treatment. Automatic controls which give command of burner input and furnace pressure have been incorporated. The authors of the paper referred to, in describing this development, have proposed a formula to define the saving over a non-permeable furnace in the case of town gas firing as follows :—

$$P = \left(1 - \frac{C - 0{\cdot}11t_0}{C - 0{\cdot}11t_2}\right) \times 100 \text{ per cent.}$$

where

P = percentage saving,

t_0 = temperature (° F.) of the furnace gases just before entering the wall,

t_2 = annulus temperature (° F.), the annulus being the chamber outside the permeable wall into which the waste gases are exhausted.

C = gross calorific value of the gas, B.Th.U./cu. ft.

The proposal raises some controversial questions, as the apparent saving would depend on this contention upon the capacity of the refractory material of the furnace to absorb heat and so lower the value of the temperature t_2. Questions which appear to require to be answered in this respect are : "To what degree must the total heat capacity of the wall be increased to accommodate the porous lining ?" "Can an increase in such heat capacity be fairly credited to the performance of the furnace ?" and "How would a heat balance of such a furnace compare with that of a furnace of identical size of working chamber and doing the same work, in which the walls and crown were constructed of hot-face insulation ?" Also, "How would two furnaces, each equipped with an efficient heat-recovery unit (recuperators, regenerators, or any other mechanism for heat recovery) compare, one with the permeable lining and one without ?" Further applications of this design and reports of furnace performance in which fuel consumption and load are related for a range of different loads, should be looked for with interest.

(IV) THE USE OF FORCED CIRCULATION OF FURNACE GASES

It is well known that radiation either from solids or gases is the major factor in heat transmission at high temperatures, and that for low temperatures convection becomes the more appreciable factor.[12] In the absence of adequate experimental work on convection in furnace chambers recourse must be had to the work done on heat transmission in boilers and heat exchangers, where the value of high flow-velocities in convection has been demonstrated, particularly in the case of fire-tube boilers. In recent years the principle of convection heating has been applied to low-temperature furnaces. The fuel is burned in a separate chamber and the products of combustion are circulated to the furnace heating-chamber through a suitable arrangement of ducts ; they are then returned for mixing with fresh products of combustion and recirculated. Fans of the centrifugal impeller type are used, constructed of heat-resisting metals capable of withstanding the range of temperatures in which convection heating is advantageous, that is, up to about 750° C. Both forced and induced circulation of the hot gases has been applied, with or without reversal of the direction of flow through the heating chamber, the gases being in circulation at such a velocity that the volume of gas circulated may be as much as 60 times the volume of the products of combustion. Forced circulation is also applied in other designs by means of propeller-type fans incorporated in the furnace chamber. This latter practice originated with electric furnaces, but in general it is less effective in attaining rapid and uniform heating than that in which the centrifugal impeller is used in a closed circuit. Thermal efficiencies of the order of 33 per cent. have been obtained in such furnaces under conditions in which soaking periods required for completing metallurgical changes have been twice as long as the period required for heating up to temperature. An extremely high standard of temperature uniformity is attainable, *e.g.* a difference of only 2° C. over a length of 25 ft., in a vertical cylindrical furnace. High rates of output are attainable where the shape and section of the charge are such that the ratio of surface area to mass is favourable, and the circulating gases are able to penetrate the charge.

A limited portion only of the fundamental data extant can be applied to this problem, as there is a scarcity of heat-transfer data applicable to furnace chambers of industrial size or to large flues. Calculations of convection in the fire tubes of steam boilers give surface conductances of the order of 10 B.Th.U./sq. ft./hr./° F., whereas values obtained in practice are materially higher, with which fact is associated the influence of gas radiation.[13] On *a priori* grounds the surface conductance due to gas radiation would be expected to increase with the length of the radiant beam, whereas the effect of convection becomes reduced with an increase in the mean hydraulic depth of the gaseous stream. On the other hand, dilution of the gaseous stream by the inleakage of cold air would result in a reduction of gas radiation, from two causes, *viz.*, the fall in temperature and the lowering of the concentration of the radiating constituents (carbon dioxide and water vapour). Heat transmission is increased with increase of velocity, but at the same time the power consumed in the circulating gases is a factor of economic importance. Although the fan power varies directly as the flow, surface conductance by convection varies with the velocity to a power which lies between 0·8 and 0·56 according to the conditions. Large-scale survey investigations are required to fill the gaps in the existing knowledge.

ORGANISATION AND METHODS FOR OBTAINING FUEL EFFICIENCY

The question of organisation for fuel efficiency in any industry may be approached in two ways. One is from the standpoint of the individual works, and the other embraces the wider considerations of the industry as a whole, together with such items of national policy as are pertinent to the issue. Both of these approaches may be affected by the corporate action of external organisations.

The previous section of this paper, in which were described some of the more recent major developments in furnace design, gave an indication of present-day trends in furnace practice. In all the cases discussed the implications with regard to fuel economy are obvious. Considerable economies can be achieved in existing plant, however, by the adoption of a firm policy directed towards that end. Indeed, despite the savings in fuel which have been effected during the war years, it is the authors' opinion that the still wider application in industry generally of the fundamental principles of combustion could result in further economies, comparable with those already realised. It is intended in this section firstly to discuss certain aspects of this question as relating to the individual works, after which some of the broader issues will be considered, and the need for progress along certain lines suggested.

FUEL SAVING IN THE INDIVIDUAL WORKS

The first essential in any systematic attempt at fuel economy is the keeping of proper records relating to fuel consumption and output. So much has been said and written on this subject that further elaboration of it is unnecessary. It is essential, however, that such records should be put to effective use and, in this connection, the need for regular plant-survey work may be mentioned. Valuable as records of plant performance are, they are capable only of exposing departures from normal practice : they do not usually indicate the cause of any such discrepancy nor do they show whether or not, or in what manner, the usual standard of performance may be improved. These facts can only be determined by the carrying out of a proper survey of the plant in question. In some cases a few simple tests, such as the analysis of samples of the furnace atmosphere, or a pressure survey of the system, may suffice, while in others a more detailed investigation involving observations over a protracted period, possibly with the help of recording instruments, may be required. The important thing is to know where the heat units are going and to this end the drawing up of a heat balance or a Sankey diagram is often helpful in presenting a clear picture of what is happening. Such a balance may be simple, giving major items only, or complex, splitting each item down into smaller units, as the case warrants.

The following typical examples illustrate the manner in which plant survey work, which is virtually a practical means of applying existing knowledge, may be used to improve performance. It will be seen that such surveys are capable of indicating the need on the one hand for modifications in the light of more recent knowledge and, on the other hand, for special maintenance work, the need for which may otherwise remain undiscovered.

(i) *A Regenerative Ingot-Reheating Furnace.*—The furnace concerned was of the batch type ; heat balances drawn up for a number of heats revealed the following :—

	Percentage of Heat Input
Useful heat in charge	7·9–20·9 (depending on the tonnage heated).
Heat in waste gases	Approx. 20
Radiation and convection losses from external surfaces.	12·9–20·4
Heat storage in furnace structure, and unaccounted for losses.	43·9–53·5

In this case it is apparent that the major loss of heat is in the furnace structure, and the appropriate lines of improvement suggested accordingly included a modification of the brickwork, with a view to the reduction of its thermal capacity.

(ii) *Comparison of Batch-type Stoker-fired and Hand-fired Rolling-Mill Reheating Furnaces.*—This particular investigation was instigated for the purpose of determining the cause of the low life of the hearth refractories in the stoker-fired furnace. The rate of fuel consumption, rate of output, waste-gas composition and temperature, and the draughting conditions were logged throughout a number of working periods ; examples of the results obtained are shown in Figs. 4 and 5. Fig. 4 gives the time variations of the rate of coal feed and the

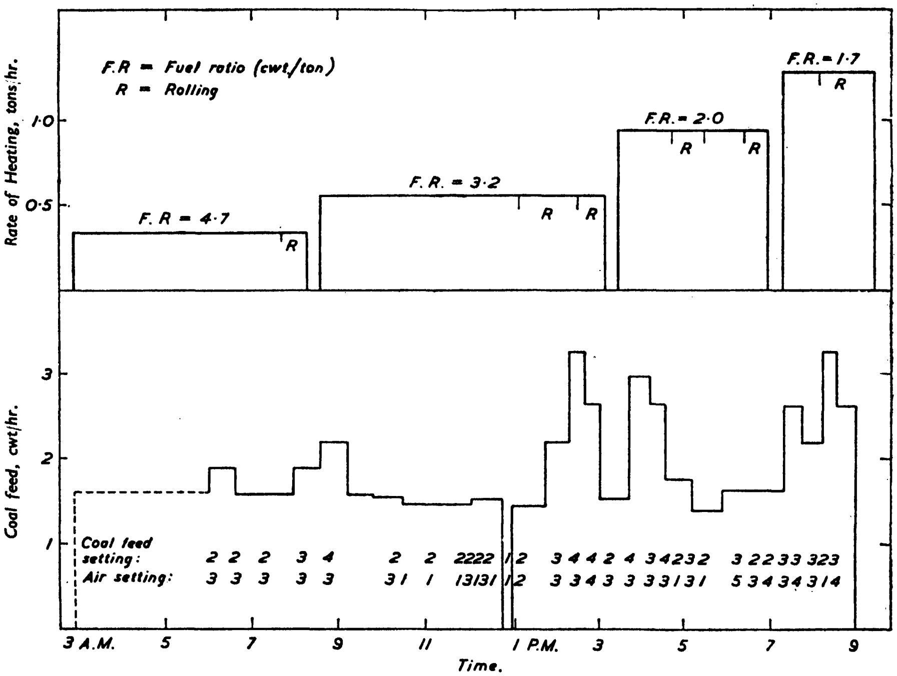

FIG. 4.—Variations in Rates of Heating and Fuel Input for Stoker-fired Rolling-mill Reheating Furnace.

rate of heating in the case of the stoker-fired furnace and illustrates the wide variations in the heating rates required (which were partly due to shop requirements). Fig. 5 is a plot of fuel ratio against rate of output, again for the stoker-fired furnace, in which the relative performances for continuous and two-shift working are compared.

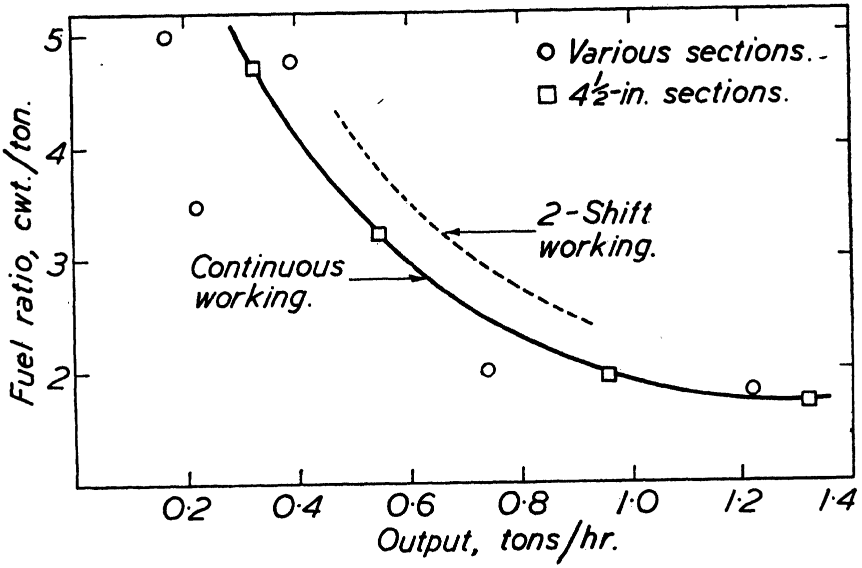

FIG. 5.—Relationship between Fuel Ratio and Rate of Output for Stoker-fired Rolling-mill Reheating Furnace.

The reason for the low life of the hearth refractories was found to be insufficiently fine control of the rate of coal feed and air flow. When these were corrected the advantages of stoker firing over hand firing were such as to make possible the attainment of a fuel economy of up to 30 per cent. The results of the investigation also indicated that a saving of from 10–30 per cent. of the fuel consumption was possible by the adoption of continuous working in preference to two-shift working.

(iii) *A Forced-Circulation, Coke Producer-Gas Fired, Heat-Treatment Furnace.*—In this case, trouble was being experienced owing to slow heating, which necessitated smaller loads, with consequent further lowering of furnace efficiency. The results of surveys of the fuel consumption, and of the temperature, pressure, and analyses of the circulating gases at different points in the system led to the following conclusions :—

(*a*) Fluctuating gas pressures pointed to the occurrence of water in the gas supply mains.

(*b*) The combustion conditions, though not ideal, were not the major cause of the inadequate performance.

(*c*) The chief cause of the slow rates of heating being experienced was leakage of the circulating gases at the reversal valve, resulting in the heating chamber being partially short-circuited.

(*d*) A contributory factor was excessive heat loss from a non-operative door seal and cracks in the furnace superstructure.

Attention to these points, together with the correct setting of the air and gas valves, resulted in a reduction of the fuel consumption per unit of output by approximately two-thirds. This saving could be attributed mainly to the fact that the improved furnace performance enabled larger loads to be carried. A comparison of the performance of the furnace before and after the adjustments were made is given in Fig. 6.

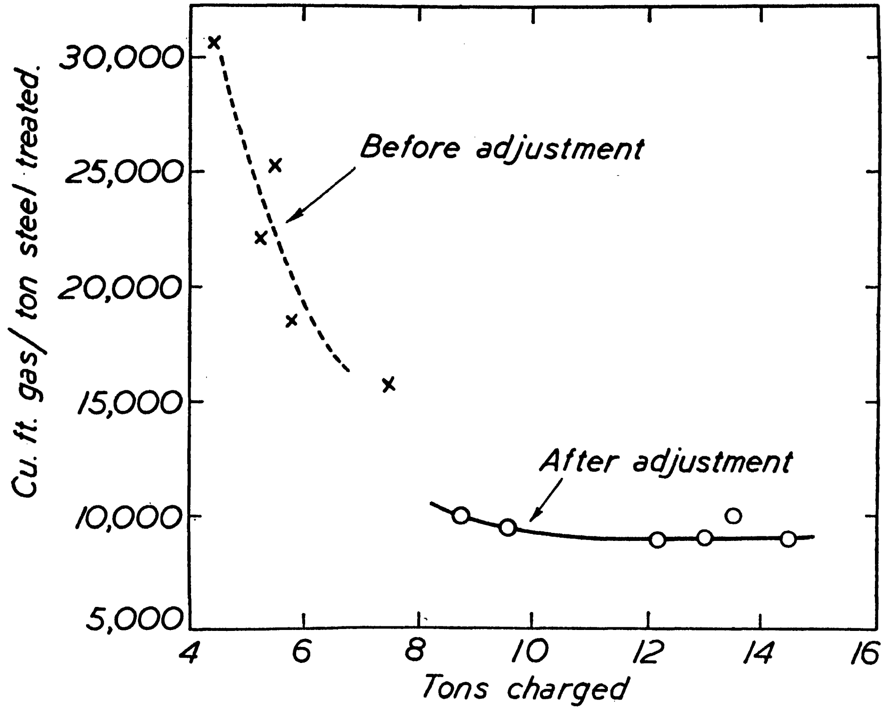

FIG. 6.—Relationship between Fuel Ratio and Weight of Charge for Forced-circulation Heat-treatment Furnace.

This was a somewhat abnormal experience, but it points to what may occur even in well-managed plants and with the latest types of equipment available, unless attention is applied in the manner described. Many more examples could be quoted, but these few should suffice to show the importance of plant survey work.

LOADING OF FURNACES—THE IMPORTANCE OF PLANNING

This problem has been repeatedly stressed in the literature of the subject. The suggestion is ventured that the main source of improperly loaded furnaces arises in the planning of the installation. The accurate forecast of shop requirements is essential. Furnaces cannot be worked efficiently if they are to deal only with occasional large masses, or to operate at the maximum practicable rate of output, or to carry loads of too variable a character. Every duty which a furnace may be called upon to fulfil is associated with specific dimensions of hearth and heating surface, as well as thickness of refractory walls and insulation, together with other factors, which are capable of enabling the maximum efficiency to be attained. While much more work in certain fields is required before it can be said that the effects of all the factors involved have been completely elucidated, sufficient knowledge of the subject already exists to warrant the expenditure of considerable thought and effort in arriving at the optimum design to suit the conditions envisaged. If, owing to some unanticipated change in shop demands, the furnace duty should change, it might actually pay, in certain circumstances, to sacrifice the existing unit and rebuild in accordance with the new requirements.

A further aspect of the subject of planning requires an examination of the whole sequence of operations undertaken. It may be possible to utilise the heat rejected from a high-temperature process in one working at a lower level, although opportunities for taking advantage of this device occur more infrequently in the iron and steel industry than in other spheres. Space-heating requirements for buildings, however, may be capable of being met by previously untapped sources of waste heat ; in this connection an example quoted by Faber in a recent paper[14] although outside the industry, is of interest. In the paper is described the manner in which low-grade heat, possibly even at atmospheric temperature, may be economically upgraded to temperatures suitable for space heating by the panel system by means of the heat pump. Several examples of large plants utilising this system, mainly on the Continent and in the U.S.A., are described, amongst which is mentioned the system installed at the Bank of England, where the source of low-grade heat is the cooling water from the Diesel engines in the power station. When one considers that in the iron and steel industry the equivalent of probably millions of tons of coal is lost annually in the form of low-grade waste heat, one does well to consider the possibilities of such schemes.

EDUCATION AND RESEARCH

For the carrying out of work of this and analogous kinds it is apparent that in the future considerably more attention must be given to the question of education than has been the practice in the past. In the fuel efficiency campaign organised by the Ministry of Fuel and Power during the war the value of education has been recognised and many requirements have been determined which should be included in the permanent structure of the educational ladder of the future. Happily, all the organisations interested are giving attention to this matter. The Institute of Fuel, in conjunction with the Ministry of Education, the Ministry of Fuel and Power, the City and Guilds of London Institute, and other important bodies are considering how provision may be made for the institution of systematic training in fuel technology for all ranks of personnel engaged or likely to be engaged on these problems in industry. The existence of an educational ladder with the possibility of qualifying at each stage constitutes an incentive to the aspirant after useful knowledge in this subject. The shortage of fuel and its economic position is likely to provide another incentive for those elements in industry which are responsible for policy.

Not only is there the problem of the man who is able to take advantage of the normal educational resources of the country, but there remains the important question of the training of the operative. In this respect new methods have to be applied. These involve primarily the matter of practical instruction, the organisation of demonstration plants, and the provision of instructors. Further, there is much scope for the type of handbook specially designed for the use of the practical man. Last but not least, there is the question of what is to be done about the man who has the obstacle of communications to contend with owing to the distant location of many important works from suitable centres where instruction may be available.

The general question of fuel research is at the moment one of some complication, and the need for co-ordination of the many-sided approaches to the problem is apparent. Co-operative work has been the keynote of scientific advance during the war ; it would be a pity if the fruitful lessons of such a development were lost.

PROBLEMS STILL AWAITING SOLUTION

In the course of the foregoing discussion many problems have already been indicated. The following is a list of further suggested lines of research, in the form of more or less major questions of general interest :—

(1) Is powdered coal to be a fuel of the future, or will the development of the mechanical stoker entirely supplant this medium ?

If the use of powdered coal in metallurgical practice is to be further developed the following factors will require attention :—

(*a*) The laws of flow of mixtures of pulverised coal and air, in particular with regard to the influence of the fineness of division and the character of the coal.

(*b*) Influence of flow velocity on the deposition of dust, and its bearing on the technique applied.

(2) Designs of gas burners in use are legion. Can some common specifications be devised which characterise the essential features of burner design for specific uses ?

(3) An investigation is required of the causes of stratification and irregularities of flow of hot gases in furnace chambers and large ducts, and the derivation of the laws of flow and pressure drop in such conditions ; the subject has particular reference to forced circulation.

(4) What is the specification of a satisfactory valve or damper and how is that specification influenced by the temperature range involved ? A specific case is that of the valve required for controlling the flow of tarry gas.

(5) In furnace hearths, what is the ideal thickness for specific uses, and what is the ideal method of construction ? How should bogie hearths be sealed to prevent air inleakage ? Can better means than at present exist be found for turning over ingots, blooms, and billets in the soaking zone of reheating furnaces ?

(6) A systematic study of the outstanding problems relating to the use of steam in iron and steelworks practice is needed.

(7) The use of the heat pump already referred to in the present paper has possibilities in connection with the recovery of waste heat.

(8) Other requirements are :—

(*a*) Simple coal meters applicable to band and bucket conveyors and to chutes.

(*b*) A heat flux-meter not involving the use of water.

(*c*) A sensitive air-meter applicable to natural-draught furnaces, for use at the air intake.

(*d*) A means to measure the stresses encountered in furnace crowns.

THE DETERMINATION OF PHYSICAL CONSTANTS

Much attention has been given in the past to the subject of heat transmission. For this work to be capable of exerting its full use it is necessary for much further investigation to be done on the determination of the physical constants involved. The laws of fluid flow at high temperatures, and the transmission of heat to and from moving gases in small ducts are fairly well understood.[15] In relation to this particular matter, the thermal conductivity and the viscosity of the normal furnace gases are known for the separate constituents of industrial gases. No relation has yet been traced, however, between the values of these individual constants and the corresponding coefficients for the industrial gases encountered in practice except in the case of viscosity at low temperatures.[16] Thus McAdams states (*loc. cit.*, p. 415) when giving the Prandtl numbers $c_p\ \mu/k$ for gases and vapours at 1 atm. pressure and 212° F. : "The effects of temperature and pressure are uncertain, and for the present it is recommended that $c_p\ \mu/k$ for gases be taken as independent of temperature and pressure, except near the critical region." The values for c_p, μ, and k are available in the literature[16] (*op. cit.*) for certain specific cases, and for certain ranges of temperature. An extension of these data appears to be called for, as well as a method for calculating the properties of mixtures of the permanent gases at high temperatures.

In dealing with the highest temperatures in industrial practice (e.g. steelmaking) the lack of high-temperature thermal data is very much apparent. The technique involved in the determination of such data is obviously difficult and tedious, and accordingly unattractive to the individual scientific worker. The determination of such constants as the latent heat of steel and of the heats of reaction of slag-forming materials leaves much to be desired, but such constants require to be definitely determined if the accurate thermal performances of high-temperature furnaces are to be measured ; numerous other advantages are also to be gained, from the standpoint of the scientific technique of the processes involved.

The questions raised in this paper are not in any sense exhaustive. The wide range of the subject would preclude any such possibility within the compass of a single communication. It is hoped, however, that the points raised will at least arouse controversy, and thereby bring into prominence those problems which would appear at the present time to be most worthy of attention.

Acknowledgment

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2. Fuel Utilisation in Iron and Steel Works

By N. H. TURNER and F. A. GRAY*

It has been said that the successive processes at present used in the manufacture of iron and steel are thermally inefficient, and that it is time that new methods were introduced. Although some justification exists for such a statement, and while it may be that the years to come will bring the desired improvements, it is in the meantime imperative to aim at making existing plants as efficient as possible, and in this way reduce the fuel consumption to a minimum.

To this end it is necessary :

(*a*) to utilise fully the by-product gases ;

(*b*) to prevent the loss of latent or sensible heat existing in the material produced, after completion of the melting or heating process ;

(*c*) to cause the necessary heat transfer from the fuel into the material being processed to take place with as high a degree of thermal efficiency as possible, and to use power in the most economical manner.

Integrated iron and steel plants represent one step towards the fulfilment of the first two conditions but much still remains to be done to recover the large amount of high-grade heat now going to waste in blast-furnace and open-hearth slags, hot coke discharged from the oven, from ingots as cast or from steel as rolled. The efficient transfer of heat and the economical use of power are receiving constant attention.

THE UTILISATION OF BLAST-FURNACE GAS AND COKE-OVEN GAS

In blast furnaces working mainly with British ores, coke consumption per ton of iron may vary from about 18 cwt. up to as high as 30 cwt. in exceptional cases, depending upon the characteristics of the furnaces and their burdens. The blast-furnace gas produced (after allowing for incidental losses) represents some 47 to 58 per cent. of the net calorific value of the coke used.

Blast-furnace services, excluding electric power, absorb, say, from 35 to 43 per cent. of the gas produced according to the efficiency and extent of the ancillary plant employed. There thus remains about 60 per cent. of the blast-furnace gas to be otherwise utilised. This represents 60 to 120 therms per ton or 10*s*. to 20*s*. per ton of iron. The utilisation of this gas is, therefore, a matter of consequence.

The generation of electric power is an obvious method and one which is commonly practised. The power requirements of a blast furnace vary greatly but where a low-grade ore is prepared according to the latest practice the blast-furnace power requirements will absorb no more than one-third of the surplus blast-furnace gas. Although it might be suggested that additional electric power could be generated and sold, this is not always a practical or an economical proposition.

It is here that the integrated iron and steel plant comes in, not necessarily as a so-called " balanced plant " (a somewhat meaningless expression possibly coined at one time to hide an excessive coke consumption at the blast furnace) but as a plant making use of all the blast-furnace gas and producing finished steel with a minimum overall fuel consumption.

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* Condensed version of a paper presented to the Iron and Steel Institute. J. of I.S.I. 1946/1.

The utilisation of blast-furnace gas can be illustrated by considering an integrated iron and steelworks making mild-steel plates as the final product.

The melting shop is equipped with open-hearth furnaces and active mixers, and shows a yield of 90 per cent. The slab mill and the plate mill give an overall yield of 70 per cent., it being assumed that the scrap from the mill is returned to the melting shop and that no intermediate product is sold. In these circumstances the melting shop can produce ingots for a heat consumption of 64–66 therms/ton, and the mill will produce plates for a heat consumption of 26–27 therms/ton of ingot, charged weight.

It is important at this juncture to emphasise the advantage of operating the melting shop with hot metal, as the heat content of the metal reaching the melting furnace can be assessed at 8 therms/ton of metal, a portion of the original heat content having virtually been lost by the metal in its passage through the mixer. The value of the heat saved is still greater when it is considered that, owing to prevailing melting-furnace efficiencies, that heat could not be replaced for a lower expenditure of fuel than that equivalent to 35 therms/ton of metal.

It is to be noted that, in the above instance, the melting shop has been assumed to operate on producer gas and that the heat consumption has been given on the basis of coal used. The consumption of blast-furnace gas in the steelworks, therefore, would be confined mainly to the mill furnaces, where it amounts to the equivalent to 32–33 therms/ton of iron produced, still leaving a surplus of at least 27 therms/ton of iron (assuming a consumption of 18 cwt. coke/ton of iron). This surplus is rather more than sufficient to generate the electric power for the blast-furnace plant ; if the coke consumption at the blast furnaces were slightly in excess of 21 cwt./ton of iron, the whole of the electric power for the blast-furnace and the steelworks requirements could be produced from surplus blast-furnace gas. If the blast-furnace operating conditions were such as to require a coke consumption much in excess of the latter figure, a considerable quantity of blast-furnace gas would be produced which could not be used, while the melting shop would still be operating on coal.

It is now common to find a coke-oven plant included in an integrated iron and steelworks. By operating the coke ovens with surplus blast-furnace gas, a supply of high calorific-value gas (coke-oven gas) is obtained which can be used, for instance, in the melting shop. In effect, the coke-oven plant may be regarded as a " transformer ", by virtue of the fact that the low calorific value of the input carbonising gas is stepped up to the high calorific value of the output gas. Moreover, the total thermal value of the coke-oven gas produced is about 2½ times that of the carbonising fuel used. It is therefore possible, in suitable circumstances, to use coke-oven gas (in conjunction with blast-furnace gas or by itself) in the melting-shop furnaces, thereby avoiding the conversion loss inherent in the use of gas producers.

Table I, based on various coke consumptions at the blast-furnace plant, shows how the fuel requirements of the various consumers can be met at a particular integrated works, assuming that the coke-oven plant produces all the blast-furnace coke required. It will be seen that, in the case of the blast-furnace plant working on a coke consumption of 18 cwt./ton of iron, to operate the integrated plant in the most advantageous manner, the coke ovens should use coke-oven gas for carbonisation. There remains sufficient blast-furnace gas and coke-oven gas for use in the melting shop and mill furnaces.

There is, however, an overall gas deficiency (excluding power requirements) of 4 therms/ton of iron which, for instance, might be balanced by producing 4 per cent. more iron and selling this surplus, or by the use of coal on the boilers. All the electric power required would have to be purchased. It may be noted in this instance that should the coke-oven plant be omitted, the melting shop would operate on coal, and the available blast-furnace gas would not be sufficient to generate all the electric power required. Therefore, merely from the point of view of surplus gas utilisation, there is no direct advantage in this case in operating a coke-oven plant.

TABLE I

HEAT AND FUEL AVAILABLE AND REQUIRED AT AN INTEGRATED IRON AND STEEL WORKS

Production and consumption are per ton of iron produced

Blast-furnace plant

Coke consumption, cwt./ton	18·0	21·0	24·0
Net coke weight, tons	0·90	1·05	1·20
Gross coke weight, tons	0·98	1·14	1·30
Net gas, therms produced	110	135	164
Blast-furnace service (excluding electric power), therms consumed.	47·3	56·0	62·5
Surplus gas, therms	62·7	79·0	101·5
Electric power required, equivalent therms*	18	19	21

Coke-oven plant

Blast-furnace coke, tons	0·98	1·14	1·30
Coal as charged, tons	1·65	1·88	2·15
Gas, therms produced	88	100	115
Carbonising gas, therms	36·3	41·3	47·0
Steam—process and boosting, etc. Gas, therms.	14·2	16·1	19·0
Surplus gas, therms	37·5	42·6	49·0
Electric power required, equivalent therms*	3·5	4·0	4·5

Steelworks

	For melting or heating, therms		For electric power, therms
Melting shop :			
1·23 tons ingots made, at 55 therms/ton	B.-F. gas 24 C.-O. gas 44	68	5·4
Soaking pits :			
1·23 tons ingots charged at 12·0 therms/ton.	B.-F. gas	14·8	18·8
Reheating furnaces :			
0·98 tons slabs charged at 18·0 therms/ton.	B.-F. gas	17·6	
Boilers	B.-F. gas	3·6	
		104·0	24·2

* 1 therm equivalent to 5·8 kWh.

Where the coke consumption is 21 cwt./ton of iron, the same general arrangement of gas utilisation would apply, but, in this instance, there would be a surplus of 17·5 therms available for the generation of electric power. If a coking plant is not included, the melting shop would again operate on coal, and the available blast-furnace gas would just balance that required for the generation of the electric power. Therefore, for the general conditions of plant operation so far assumed, this coke-consumption figure represents the borderline beyond which the operation of a coke-oven plant becomes a material factor in the utilisation of surplus gas.

There are at times deficiencies in the production of blast-furnace gas, due to irregular working of the blast furnaces and maintenance repairs, etc. These conditions have to be given full consideration when assessing the merits of power purchased versus power generated and the need for gas storage and units fitted for the use of alternative fuels. In the case of power generated, it has to be decided whether it should be obtained from gas or steam-operated units, bearing in mind the ease and quickness with which a boiler can be changed over from blast-furnace gas to a standby fuel. These are considerations to weigh against a possible loss in thermal efficiency.

What the position will be with the advent of gas turbines is not clear, as the development may take place along lines which have the same advantages with regard to standby fuels as possessed by steam today.

When considering the complete utilisation of the blast-furnace gas produced, consideration must also be given to the effect of future developments in the preparatory treatment of ore on the quantity and quality of the gas produced and available.

Future developments in blast-furnace practice may also take the form of oxygen enrichment of the blast, which, if adopted, will raise many problems in gas utilisation and distribution. Whatever line future development may take, an adequate gas storage and a sufficient number of heat-consuming units will have to be equipped for the use of alternative fuel.

GAS CONTROL

When the operation of the steelworks depends largely on the supply of blast-furnace and/or coke-oven gas, it is necessary to arrange a system of co-ordination of gas production and distribution. The co-ordination can best take the form of a properly manned and equipped gas control station, but in its absence a makeshift organisation will go a long way towards eliminating potential trouble.

INSTRUMENTS AND CONTROL

The basis of fuel control is measurement. The benefits to be derived from the judicious use of industrial measuring instruments in the achievement of fuel economy have now been fully recognised and wherever the works management is progressive, full consideration is given for the provision of such instruments.

The use of automatic regulators for the control of air and gas volume, pressure and temperature, has developed to such an extent that it may soon be necessary for plant items to be designed for being automatically controlled, rather than simply having automatic controllers fitted to them.

APPLICATION OF BY-PRODUCT GASES

INTEGRATED WORKS

In integrated works, apart from considerations of economics (which may have the larger bearing on the question), the choice of where best to utilise the by-product gases should resolve itself for furnaces into considerations connected with temperature to be obtained and metallurgical factors. With boilers the chief consideration is the necessity for making provision for the use of auxiliary fuels.

NON-INTEGRATED WORKS

When coke-oven gas is available in non-integrated steelworks, it offers decided advantages as a source of high-grade heat. Care should be taken to ensure that this gas is applied, as far as possible, to processes where it can be utilised to the best thermal advantage. The replacement value of coke-oven gas varies according to the purpose for which it is used ; speaking generally, and from the standpoint of economics, it has its greatest value when used in small heating furnaces and its lowest value for drying purposes, or as a supplementary fuel for steam raising.

Increases in thermal efficiency of from 15 to 50 per cent., together with increased output, are possible by the replacement of producer gas and direct coal firing by coke-oven gas firing in reheating furnaces. The increased efficiency attainable varies, of course, according to the efficiency of the furnace before conversion.

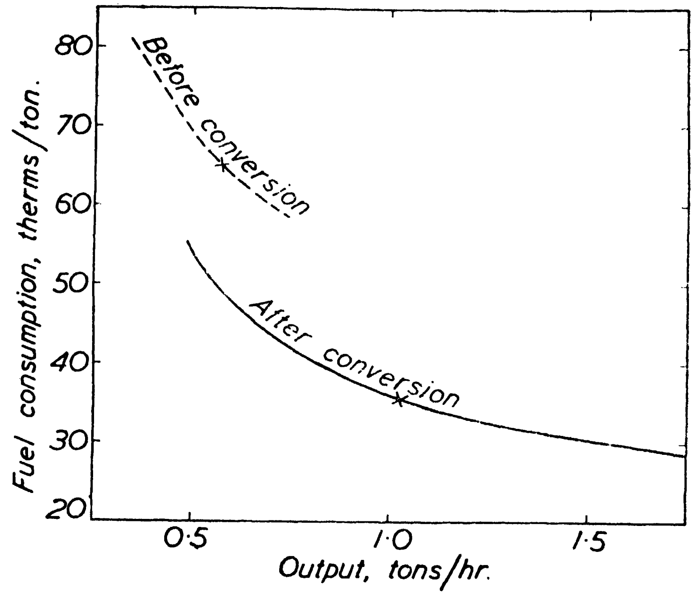

FIG. 7.—Heat Consumption—Output Chart.

The reduction in heat consumption per ton and increase in output per hour possible by the conversion of a direct coal-fired furnace to coke-oven gas firing is illustrated by the heat consumption—output chart given in Fig. 7. In this particular case the converted furnace is now doing the work of two coal-fired furnaces.

HEAT CONSERVATION

The open-hearth furnaces in a steelworks are the major fuel consumers and for this reason demand special attention. It is desirable that technical staff be allocated to, and entirely engaged upon, fuel utilisation and control in the melting shop.

Good instrumentation is essential for the guidance of the furnace operator and to provide data for the efficient control of the furnaces.

Open-hearth furnace design has not fundamentally changed since the introduction of the process, and there is considerable scope for research on the subject.

The principle of heat regeneration, which made the open-hearth furnace practicable, has paved the way for general development of the technique of heat recuperation.

The defects inherent in brick regenerators and recuperators have led to increased use of the metal recuperator, especially for temperatures below 800° C. The application of waste-heat boilers to furnaces provides a suitable method for recovery of heat in flue gases, which cannot otherwise be returned to the furnace. The best case for a waste-heat boiler can usually be made for a unit with a large heat throughput, provided, of course, that the temperature of the waste gases is sufficiently high. The open-hearth furnace is a typical example of such an application.

As regards heating furnaces (with the exception of direct coal-fired furnaces) working at temperatures up to 1350° C., these can and should be designed to make waste-heat boilers unnecessary.

As far as heat conservation in general is concerned, there are stages in the steel-making process where more care should be taken as, for example, between ingot stripping and rolling. Without efficient planning, much heat loss is likely to occur especially with those plants operating large tilting furnaces. Some relief may be obtained by the use of Gjers pits, but particular attention must be paid to the design to ensure that their heat capacity is at a minimum so that no more heat is lost from the ingot than is necessary to permit the temperature to even itself across the ingot section during the passage through the soaking pits.

PROGRESS ACHIEVED

In 1930, fuel departments were started in all the main works of the United Steel Companies to give specialised attention to the important subject of fuel economy. As a result of close co-operation with the works departments definite progress has been made. It is proposed to refer to one or two items of progress which illustrate points raised earlier in the paper.

GAS DISTRIBUTION AND CONTROL

In 1933, a coke-oven gas supply was introduced with the completion of a pipeline connecting the Templeborough Steelworks with the United Steel

Companies' Orgreave coke-oven plant. This measure formed part of a development policy which today is being carried a stage further. The gas distribution system is illustrated diagrammatically in Fig. 8.

The gas supply from the Orgreave coke ovens is to be increased following the completion of additional ovens and the laying of a new 18-in. pipeline over a distance of 14 miles to the works of Samuel Fox and Company.

INSTRUMENTS AND REGULATING EQUIPMENT

The extent to which instruments and automatic-control equipment are now being used is illustrated by the following examples of what is provided on the latest open-hearth and continuous reheating furnaces :—

Open-Hearth Furnaces

Gas-pressure regulator(s).
Gas-pressure recorder(s).
Gas-flow recorder(s).
Air-flow recorder.
Furnace pressure recorder and controller.
Gas-checker draught recorder.
Air-checker draught recorder.
Stack-draught recorder.
Roof-temperature recorder.
Checker-temperature reversal indicators.
Checker, flue-gas and gas temperature recorder(s).

Continuous Two-Zone Slab Reheaters

Total blast-furnace gas flow recorder.
Total coke-oven gas flow recorder.
Mixed-gas flow recorder.
Blast-furnace gas pressure indicator.
Coke-oven gas pressure indicator.
Mixed-gas pressure indicator.
Gas-mixture regulator.
Gas-mixture pressure regulator.
Furnace-temperature recorder and regulator on each zone.
Six-point furnace temperature indicator.
Air/gas ratio regulator on each zone.
Furnace-pressure regulator on each zone.
Furnace-pressure recorder.
Reversal controller.

At the Appleby-Frodingham works, there are some 1,500 instruments in use. For the maintenance of these instruments, there is a fully equipped instrument repair shop, with a present staff of twenty. This repairs shop has been in operation for the past fifteen years.

THERMAL INSULATION

At all the works, much attention has been paid to the use of thermal insulation for the prevention of heat loss. At Appleby-Frodingham, this activity culminated in the formation of a heat insulation department.

BOILERS

At the Stocksbridge works, following experimental trials, a specially designed boiler with a capacity of 25,000 lb./hour, has been installed to burn a low grade colliery washery refuse containing 35 to 42 per cent ash, with a small admixture of boiler slack containing 15 per cent ash. The refuse, a product of the washery

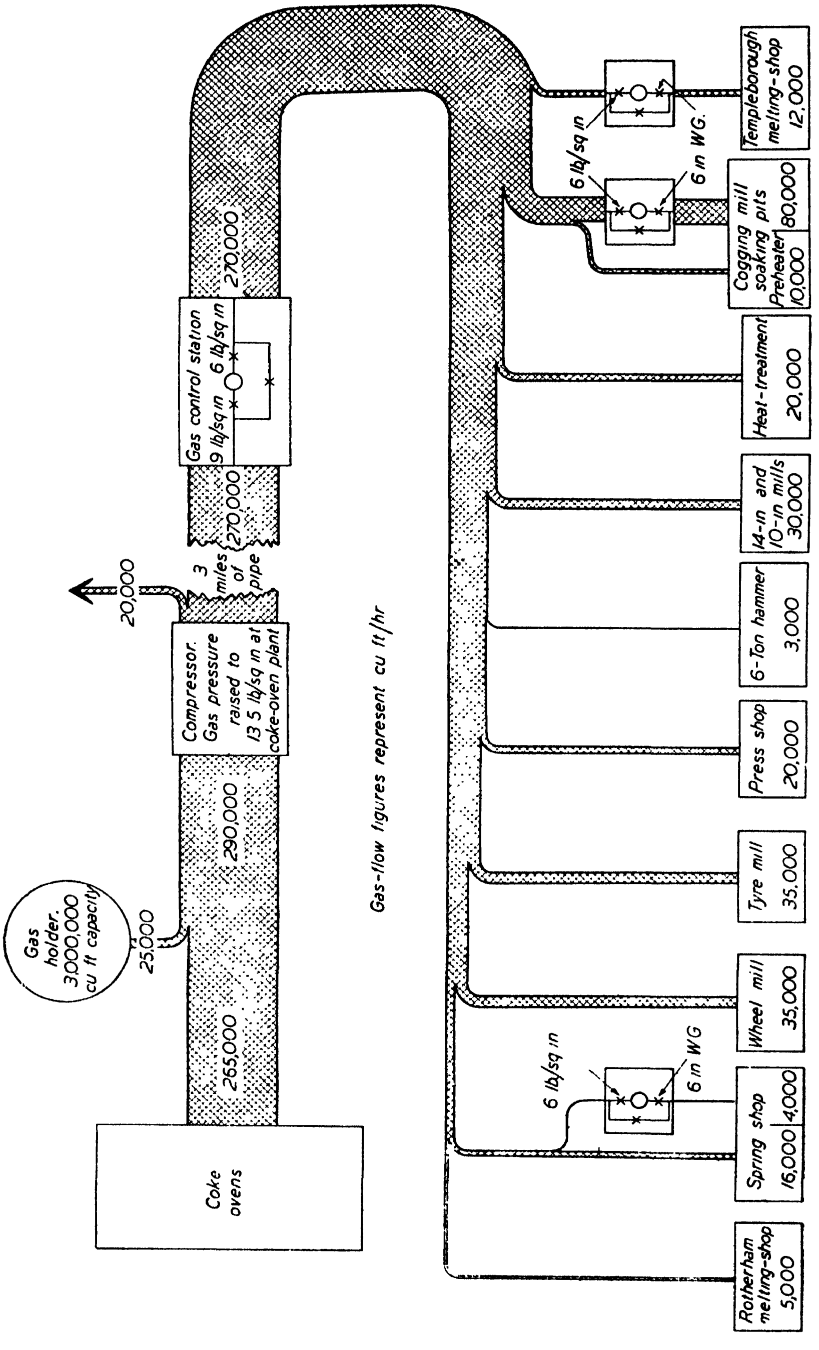

FIG. 8.—Gas Distribution System to Steelworks.

at Stocksbridge Colliery, was previously unusable in existing boilers and had to be dumped. This boiler is effecting a saving of 5,200 tons of good coal per annum.

Acknowledgment

The authors wish to thank the management of the United Steel Companies and Associated Companies for permission to present this paper.

3. Fuel Considerations in the Fabrication of Non-ferrous Metals and Light Alloys

By LESLIE AITCHISON, D.MET., M.SC., F.R.I.C., F.R.AE.S.*

[This paper was printed in full by the British Non-Ferrous Metals Federation of 132, Hagley Road, Birmingham. Copies are available on application to the Federation.]

The paper presents a comprehensive survey of the factors affecting the efficient use of fuel in those copper and brass industries concerned with the manufacture of wrought goods, and similarly for wrought aluminium and aluminium alloys. Primarily it deals with the operation of furnaces, either for melting or for reheating, annealing, hot rolling, forging or extrusion ; but also considers fuel consumption in heating and lighting, and the achievement of fuel economy through the most efficient employment of power-driven plant.

It is shown that in the industries considered, the cost of fuel and power is comparatively low in relation to other production costs, particularly metal and labour ; and that the policy in regard to fuel is greatly affected by other operating factors, as well as by general economic considerations in relation to production. Fuel economy in the non-ferrous industries must be considered in conjunction with all the economic aspects of fabrication. In relation to furnace work these factors are as follows :

(*a*) the capital cost of the furnace and its installation ;
(*b*) the cost of the space required to house the furnace and its ancillary parts ;
(*c*) the labour required to operate the furnace and the degree of skill such labour should possess ;
(*d*) the power required to drive the furnace ;
(*e*) the quantity of fuel used per ton of metal treated and its price per thermal unit ;
(*f*) flexibility of operation, permitting rapidity of heating when desired;
(*g*) accuracy of control and uniformity of heating ;
(*h*) speed of operation ;
(*i*) design conditions that permit of equally economical working on both large and small charges and throughput ;
(*j*) effect on the surface state of the metals treated ;
(*k*) metal losses in the process ;
(*l*) reliability, durability and maintenance ;
(*m*) capacity and throughput ;
(*n*) ease of working (*i.e.* charging, discharging, tapping, etc.) ;
(*o*) comfort of the operatives.

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In the non-ferrous industries, particularly those concerned with brass and copper, the unit of production is usually comparatively small, and a large variety of alloys of different compositions must necessarily be handled in the same plant. Conservation of metal is of prime importance in all non-ferrous industries, in view of the high price of the basic materials, and economies in the use of fuel are unlikely to be adopted if they involve any increase in process losses.

As sources of heat, consideration is given to coke, fuel oil, creosote/pitch, town gas and electricity. The following tables show the theoretical consumption of such fuels in melting and in reheating, and indicate also what may be regarded as acceptable practical figures of consumption.

Melting

Metal	Fuel	Mean calorific value	Theoretical consumption therms	Theoretical quantity of fuel per ton of metal	Present acceptable consumption per ton of meta
Copper . .	Coke	291 therms per ton	7·08	0·0243 tons	0·20 tons (coal
60/40 brass .			5·92	0·0203 ,,	0·23 ,, (coke
70/30 brass .			6·16	0·0211 ,,	0·26 ,, (coke
Aluminium alloy			10·9	0·0375 ,,	0·26 ,, (coke
Copper . .	Fuel oil	1·76 therms per gall. or 424 therms per ton	7·08	4·02 galls.	30 galls.
60/40 brass .			5·92	3·36 ,,	20 ,,
70/30 brass .			6·16	3·50 ,,	24 ,,
Aluminium alloy			10·9	6·19 ,,	—
Copper . .	Creosote/ pitch	348 therms per ton	7·08	0·020 tons	0·27 tons
60/40 brass .			5·92	0·017 ,,	0·20 ,,
70/30 brass .			6·16	0·018 ,,	0·23 ,,
Aluminium alloy			10·9	0·031 ,,	—
Copper . .	Town gas	1 therm per 222·2 cu. ft.	7·08	1,573 cu. ft.	—
60/40 brass .			5·92	1,315 ,,	9,500 cu. ft.
70/30 brass .			6·16	1,368 ,,	—
Aluminium alloy			10·9	2,421 ,,	7,100 ,,
Copper . .	Electricity	0·034 therms per kWh.	7·08	208 kWh.	—
60/40 brass .			5·92	174 ,,	210
70/30 brass .			6·16	181 ,,	250
Aluminium alloy			10·9	320 ,,	400

Reheating

60/40 brass .	Coal	310 therms/ ton	2·90 therms	·0093 tons	0·150 tons
	Fuel oil	1·76 therms/ gall.		1·79 gall.	7·3 galls.
	Creosote/ pitch	348 therms/ ton		·0083 tons	0·030 tons
	Town gas	222·2 cu. ft. therm		644 cu. ft.	2,200 cu. ft.

* Large unit.

The part played by good management in achieving fuel economy is examined in its various aspects. The importance of the continuous working of melting furnaces is illustrated, the consumption figures given in the following table for brass melting in single shift as compared with continuous working being a typical result.

	Days only	Days and nights
Number of heats . .	51	122
Metal melted, tons . .	15·08	36·05
Consumption . . .	4,264	7,407
kWh./ton melted . .	283	210

Parallel evidence from practice in melting light aluminium alloys is given n the next table.

Period	Metal melted, tons	Fuel used, tons	Fuel/metal ratio
1	680	170	0·25
2	660	172	0·26
3	630	170	0·27
4	570	168	0·29
5	560	165	0·29
6	430	150	0·35

Similar data is provided in connection with the full and the inefficient operation of plant. The importance of correct furnace design resulting in the maximum transference of heat units to the metal in the furnace is demonstrated ; while full consideration is given to the achievement of fuel economy through the correct control of all metallurgical processes reinforced by the accurate and regular recording of consumptions of fuel and power. The importance of efficient plant maintenance is emphasised.

The technical aspects of fuel economy are usually of a long-term nature, as are the economic factors which have been mentioned. Effective short-term measures resulting in considerable economies can be achieved, however, through good management, and by the closest and most intelligent co-operation of operatives and controllers. Many illustrative examples, particularly connected with the operation of furnaces of different types, are provided.

4. Fuel Efficiency in the Brassfoundry Pays Dividends

By G. L. HARBACH, A.I.M., and F. HUDSON, F.I.M.

INTRODUCTION

This paper has been prepared on behalf of the Association of Bronze and Brass Founders at the request of the Ministry of Fuel and Power. It is intended to review the early work of the Association and the results achieved in connection with fuel economy ; to provide comparative data on coke and oil-fuel melting, and to give examples of further economies which may be adopted more generally in the future.

FORMATION OF A.B.B.F. AND THE TECHNICAL COMMITTEE

The primary reason for the formation of the A.B.B.F. in 1942, was the urgent need to save fuel. The committees, sponsored by the Ministry of Fuel and Power, required representation of the industry by a national body capable of devising means of effecting fuel economy in the foundries concerned.

Prior to this period founders of bronze and brass had no national organisation to deal with their special interests, but the records of the past four years and the increasing membership are evidence of the advantages of the Association, both to individual members and the industry as a whole.

A technical committee was formed from non-ferrous foundrymen and metallurgists who were all prepared to pool their knowledge and experience for the general benefit of members. The field of interest and usefulness quickly proved to be far wider than the original object of fuel economy, as shown by the recently published report (" Foundry Trade Journal ", 18th July, 1946) and the number of members who have been assisted in solving many technical problems.

SUMMARY PROVIDES YARDSTICK

Up to 1942 reasonable fuel consumptions for different foundry processes were largely unknown ; most firms knew something of the fuel used as a whole, some had detailed information, but few knew how their results compared with others working under similar conditions—a yardstick was necessary to determine fuel efficiency.

The first work of the technical committee was to circularise all members with a comprehensive questionnaire and summarise their replies. The data obtained were tabulated to show :—

(1) Firm's reference number.
(2) Output in tons.
(3) Different fuels all calculated to " tons coal equivalent " on a thermal basis.
(4) Types and capacities of furnaces.
(5) Types of castings produced—green sand, dry sand, centrifugal, chill, etc.
(6) The proportion of the various alloys cast.
(7) Fuel used per ton output.

Copies of the summary, which covered a complete cross-section of the industry, were sent to each member, together with comparative statistics in cases where the ratio of fuel to output differed widely although conditions were similar. By this means each firm could determine its own yardstick, by comparing results with others engaged in similar work, and take steps to explore the causes and effect reductions where fuel consumption was high. The results were gratifying in that the Association's quarterly returns showed considerable fuel savings.

REPORTS TO MINISTRY OF FUEL AND POWER

The Ministry required progress reports in a more condensed form than the summary and while the varying manufacturing conditions naturally associated with any branch of the foundry industry caused the " fuel used per ton output " to differ widely, the fuel consumption figures fell broadly into three groups : green sand, dry sand, and remainder. At the request of the Ministry, the Association also compiled statistics for the billet and ingot producers and the data from this section proved very useful as they provided a further group, the fuel consumption of which was almost entirely devoted to melting. (See Table I.)

TABLE I

FUEL CONSUMPTION—VARIOUS PROCESSES

Tons coal equivalent per ton produced

Group No.	Production	Range	Average
1	Billets and ingots	0·15 to 0·52	0·301
2	Over 70 per cent. green sand castings . .	0·42 to 1·85	0·900
3	Over 70 per cent. dry sand castings . .	0·49 to 2·46	1·44
4	Mixed (not in Groups 2 or 3) . . .	0·20 to 4·30	0·866
2, 3 and 4	Combined	—	0·906

Note.—Group 4 included a wide variety of products and processes some using very little fuel, others using much above the average, as indicated by the wide range.

The comparative results of the records of the first two years were issued to members and the Ministry, as a condensed summary under the four group headings shown in the Table.

Each member could see at a glance his position in the group, and any change which had occurred during the year while the Ministry officials had a ready means of judging the situation as a whole.

FUEL SAVINGS EFFECTED

The work of the technical committee provided the industry with new knowledge and, by its practical application, considerable fuel savings were effected as shown by the following report of the Association for 1942–43.

" *Billet and Ingot Makers.*—For 27 firms the specific fuel consumption ton/ton was reduced from 0·301 to 0·295, a fuel saving of 2 per cent. or 411 tons for the 27 firms ; 15 firms showed decreases, six firms claimed over 15 per cent. reduction.

" *Bronze and Brass Castings* (*three groups combined*).—For the 51 firms making returns in both years the specific fuel consumption ton/ton was reduced from 0·906 to 0·862, representing a 4·4 per cent. saving, calculated to be 2,500 tons per annum ; 36 firms showed decreases, 11 firms claimed 25 per cent. or more."

Further savings in fuel were reflected in the returns for 1944.

Summing up this section of the paper, it is felt that the " yardsticks " produced for the various processes, combined with advice and propaganda, not only resulted in a reduction of both fuel and costs, but achieved a worthwhile lasting benefit to individual firms and to the industry as a whole.

FUEL SAVING METHODS REVIEWED

The means whereby fuel saving was accomplished had wide publicity in 1942–43 ; however, the following points are worth repetition, because the urgent needs of war production frequently prevented all the possible economies being effected at the time, and where they were achieved there may have been a falling off since, through lack of interest.

The working programme should arrange that :—

(1) Moulds be completed when the metal is ready to pour—" stewing " spoils good metal apart from fuel wastage.
(2) The minimum number of furnaces be used each day.
(3) Each heat to be as near maximum capacity as possible.
(4) Crucibles below normal size for a furnace are not used.
(5) Pre-ingotting of virgin metals to be avoided.

The success or failure of any fuel-saving scheme ultimately depends on the operator. The authors, satisfied from personal experience, that evidence of interest in a man's job and the result he achieves is the best means of ensuring intelligent co-operation, recommend the following addition :—

(6) All operators using fuel should be made aware that :—
  (*a*) it is necessary to use fuel with care.
  (*b*) the management are interested in the results.

The scope for future fuel economy may be judged from the facts that earlier efforts were limited by the urgency of war needs, and the restrictions on new plant and choice of fuel. With the knowledge previously gained applied to old plant, the installation of highly efficient fuel-burning equipment which is now practicable, and the availability of oil fuel to replace coke, the following examples show that further savings on a wide scale are now possible.

OIL FUEL COMPARED WITH COKE

It has been recommended officially that oil fuel should be used where possible in place of solid fuel. Here it must be stated that oil fuel does not necessarily mean creosote/pitch, and disappointed users of this form of fuel—and not all are anxious to revert to coke firing—may still consider the official recommendation with advantage.

Potential users will naturally wish to know how the change will work out and, with this end in view, a review of the summary was made to extract the fuel consumptions of oil-fuel users. The results are given in Table II from which it will be seen that firms using oil were, on a thermal basis, more economical than those using coke.

TABLE II

CONSUMPTION AND COST OF COKE AND OIL COMPARED

Production	Fuel per ton produced				
	Coke actual tons	Oil C.E.* tons	Oil actual tons	Cost†	
				Coke	Oil
				s. *d.*	*s.* *d.*
Billets and ingots . .	0·31	0·25	0·175	25 10	34 6
Green sand castings . .	1·01	0·625	0·428	84 0	84 6

* Coal equivalent—coke 280 therms per ton, oil 400 therms per ton.
† Based on coke at 83*s*. per ton, and Diesel-type oil at 9¼*d*. per gallon of 8¾ lb.

On a thermal balance 0·7 ton of oil equals 1 ton of coke, but the unit cost of oil is approximately 2½ times that of coke, so, for the same outlay on fuel, roughly 0·4 ton of oil should give the production of 1 ton of coke. The billet and ingot group show a 33 per cent. increase in cost but the efficiency in the green sand casting group was sufficiently high to offset the higher cost of oil. In the other groups there were insufficient oil users to make a comparison.

However, cost as delivered is not the sole criterion on which oil fuel should be judged when compared with coke ; general convenience in storage and handling from truck to furnace, no ash disposal and a cleaner furnace all decrease labour costs ; and economies are effected by no discard in ashes and " smalls ", and quicker melting, particularly for high-temperature metals. All these factors favour the use of oil and it is significant that users of oil fuel evince no desire to return to coke.

ACTUAL EXAMPLES OF FOUNDRY DIVIDENDS

It is obvious that the benefits gained, from the more efficient use of fuel, by the non-ferrous foundry industry as a whole have been obtained as a result of the work done by individual foundries. During the war patriotism may have been the incentive, but today the progressive foundryman appreciates that fuel efficiency is an integral part of a well-run business and when intelligently applied is capable of returning substantial dividends. Circumstances do not permit the giving of many examples of such dividends but it may be of interest to outline the results obtained by two foundries :—

(A) Due to making the best use of existing melting equipment, and
(B) due to the installation of new mould and core drying ovens.

These examples have been selected in view of the fact that the bulk of the fuel employed centres around these operations and they are common to all foundries large and small.

DIVIDENDS DUE TO MAKING THE BEST USE OF EXISTING MELTING EQUIPMENT

Foundry A operates batteries of natural and forced draught coke-fired crucible furnaces of both the pit and tilting type for the production of bronze and brass castings to meet general engineering requirements. Their equipment and products are similar to those of other foundries throughout the country although their production may be greater than many. The following is an extract from their cost accountant's report :—

> Our standard allowed cost of fuel for melting has not been altered since January, 1942, and since our fuel account shows that the amount of fuel used is still less than the amount allowed, we see no reason for altering our standard. This means, of course, that all the price increases for fuel which have occurred since January, 1942, have been absorbed as a result of efficient operation. The following figures will show quite clearly what has happened.

Year	Standard allowed cost for fuel	Actual cost of fuel	Saving
	£	£	£
1942–43	14,197	12,127	2,070
1943–44	14,595	11,064	3,531
1944–45	12,001	11,423	578
1945–46 (8 months to date) . .	7,516	7,464	52

> While the saving has been falling, except for the year 1943–44, it must be remembered that we are still operating on the standard fixed for

January, 1942. Since January, 1942, the basic price of fuel has increased by 31·875 per cent., so that if we bring the period for the last eight months into line with the price increases we should have :—

Standard allowed cost for fuel	£9,912
Actual cost of fuel	£7,464
Saving	£2,448

which in the full year provides a saving of £3,672 or £1,600 above that shown for the period 1942–43. In other words, if it were not for our fuel economy campaign, we should expect to have £1,600 greater expense on fuel in the year 1945–46, than actually is the case.

This dividend has been achieved along the usual lines with one very important exception. We have allowed our furnacemen to finish work and go home when the last mould has been poured. Departments have been encouraged to arrange their work so that this can be achieved at the earliest possible moment of the day. The result has been that although the volume of tonnage moulded has been satisfactorily maintained, the furnacemen have been working something like 30 to 36 hours a week instead of 47. Since, however, they are paid on a piecework basis, this has not affected their earnings but the effect upon fuel economy can be appreciated.

The fact that the company includes in its cost accounts, fuel at a standard set in January, 1942, and is operating from this basis, shows how satisfactory the position is, since obviously we should not form selling prices based upon overhead figures which would show us a loss.

DIVIDENDS DUE TO THE INSTALLATION OF NEW MOULD AND CORE DRYING OVENS

Foundry B used to employ old-fashioned horizontal ovens for baking two batches of oil-sand cores per day. It was decided to instal a modern type of vertical continuous stove and the following results were obtained :—

	Using old batch type stoves	Using modern vertical continuous stove (No. 2 Acme Junior)
Oil-sand cores baked per day	3,200 lb.	7,000 lb.
Fuel used per day (coke)	672 lb.	280 lb.
Period in operation	Two batches 11 a.m. to 1 p.m. and 5 p.m. to 7 p.m.	Continuously 6.30 a.m. to 7.30 p.m.
Fuel consumed per hour	168 lb.	22 lb.

In other words, one modern drying unit provided a daily output of baked cores equal to the production of two obsolete batch-type stoves with an approximate saving of just over half-a-ton of coke a day.

It is interesting to note that oil can be successfully employed for firing mould and core drying stoves. It is claimed that between five and seven tons of oil-sand cores can be baked an hour at 425° to 430° F. (218° to 221° C.) on this installation with the consumption of four to five galls. of light oil (Diesel) which gives a maximum fuel cost of around 10*d.* a ton of dried cores. It should be noted that this stove was specially designed for oil firing with the result that a high efficiency has been obtained. Conversions, or the use of higher operating temperatures, are not so economical and it might be of interest to mention that a stove of similar size and output to that outlined above converted from coke to oil firing and operating at 500° to 510° F. (260° to 265° C.) required 10 galls. of oil per hour. With oil firing there is need for careful burner control otherwise oil is wasted and the surface of the cores becomes covered with soot.

It is appreciated that the examples just given relative to modern methods of drying cores apply to foundries with a large output, but it should be recognised that miniature editions of the above plant are now available for the small brassfoundry. A vertical continuous core stove has recently been designed measuring 12 ft. 6 in. high, by 5 ft. by 4 ft. 5 in., to meet the needs of the small core shop. This stove is gas heated and fitted with automatic temperature control, and, while its fuel efficiency will be somewhat less than the larger units previously outlined, it will permit of very substantial fuel savings over the numerous old-fashioned and obsolete equipments still in service.

CONCLUSIONS

In the past fuel has been cheap and regard has been casual in consequence ; present-day costs, having brought it more into line with its importance as a major national asset, make the wise use of fuel imperative. Under wartime impetus great strides were made within the limitations of that period, but restrictions on choice of fuel and the installation of new equipment are now easier, and improved efficiency and further economies can still accrue from thoughtful and active consideration by foundry executives, coupled with co-operation and interest in the operator's efforts.

Fuel saving and the use of modern economical plant are frequently accompanied by labour saving—both of considerable national importance to production in all its branches—and, as castings are the raw material for engineers and their products form a large proportion of our exports, every improvement in fuel efficiency improves the national position.

As a country dependent on exports to maintain its standard of living, Britain is in competition with other countries which have developed a high state of industrial efficiency and, unless this country too reaches a similar high standard, it will fail to retain a leading position. The efficient use of fuel in the foundry industry may seem a small item, nevertheless, it adds its quota to the whole, and fuel economy not only pays dividends in brassfoundries but, as a factor in the overall efficiency necessary for the country's welfare, it pays national dividends too.

5. Saving Fuel in the Glass Industry

By R. HALLE, B.SC. TECH., PH.D.

I. INTRODUCTION

The object of this paper is to review the present standard of fuel efficiency obtained in the glass industry, and to examine the possibilities of further improvements and developments in the near future.

Before proceeding with this account it may be useful to refer briefly to the types of fuels and furnaces used in the glass industry. The following fuels are employed :—

(1) Solid fuels : coal and coke.
(2) Liquid fuels : light oils, heavy oils and creosote/pitch.
(3) Gaseous fuels : producer gas, coke-oven gas, town gas, Mond gas.

Of the *solid fuels*, coal constitutes the main source of fuel. Except for steam raising, the amount used in the solid form is negligible. The bulk of the coal consumed in the glass industry is converted into producer gas for furnace heating. Coke is used in comparatively small quantities in auxiliary operations, such as the heating of some pot arches and of a few earlier types of annealing furnaces.

As regards *liquid fuels*, oil firing for melting glass has been in use for a considerable time. During the war creosote/pitch has been employed extensively.

Of the *gaseous fuels*, producer gas still remains the most widely used, chiefly on account of the fact that in most cases it is the cheapest fuel available. Apart from producer gas there are three other gaseous fuels in use in the glass industry, namely, coke-oven gas, particularly in Yorkshire and the North-East coast ; town gas, which is used both for melting purposes and for auxiliary heating purposes ; and finally, Mond gas which has been employed to a limited extent in South Staffordshire.

The following chief types of furnaces are used in the glass industry :—(i) pot furnaces, (ii) tank furnaces, (iii) annealing furnaces, (iv) miscellaneous furnaces or heating appliances, such as pot arches, glory holes, etc.

A fuller account of the fuels and furnaces used in the Glass Industry has appeared in the Ministry's text book "The Efficient Use of Fuel", and the brief outline given above must, therefore, suffice, except to stress the fact that the prime object of a glass melting furnace is to make glass of good quality, in the required quantities, at the right time and at the most economical figure. This statement may appear self-evident, but it is important to realise that, to quote E. Seddon, "glass quality and furnace pull cannot be sacrificed to fuel economy, they must be reconciled with the saving of fuel."[1]

It is against this background that an outline will be given of the question of fuel efficiency in the glass industry. For the purpose of considering the problem in its proper perspective, and to assess the possibilities of future savings, it is important to take into account the progress the glass industry has made in the past with respect to its efficient utilisation of fuel. Section II of this paper will, therefore, contain a brief record of developments in fuel efficiency between 1914 and 1940. Section III will deal with the fuel efficiency campaign carried on in the glass industry during the last five years. The lines of future progress and development will be outlined in Section IV. A brief reference to oil firing will be made in Section V and some general conclusions will be given in Section VI.

II. RECORD OF FUEL EFFICIENCY BETWEEN 1914 AND 1940

The glass industry has always taken a very keen interest in all problems concerned with the utilisation of fuel. The very first volume of the Journal published in 1917 by the Society of Glass Technology contained two papers on the heating and design of glass furnaces. That initial interest has been well maintained and up to the present 66 papers on fuel and furnace problems have been published in the Transactions of the Society's Journal.

In 1927, the Council of the Society of Glass Technology set up a Committee which was, to quote from the minutes, " to deal specially with furnace operation, design and efficiency." Since that time this committee, on which both glass manufacturers and furnace builders are represented, has actively pursued these subjects and has made many valuable contributions.

1. IMPROVEMENT IN RATE OF MELTING AND REDUCTION IN COAL CONSUMPTION PER UNIT OF OUTPUT

The following two examples[2] will serve as a practical illustration of the progress made with regard to increased rate of melting and reduced fuel consumption. Fig. 9 indicates the remarkable improvement in output from a furnace which has remained practically the same in area throughout thirty years. Seven times the weight of glass was obtained in 1937 compared with 1907. At the same time, the glass to coal ratio expressed as tons of glass per ton of coal, including coal for steam, has increased from 0·5 to 2·45. Data for another tank furnace, summarised in Table I, with a melting area of 450 sq. ft., show similar progress in the average melting rate expressed by the number of sq. ft. of glass surface of the melting chamber of the furnace required to melt one ton of glass per 24 hours.

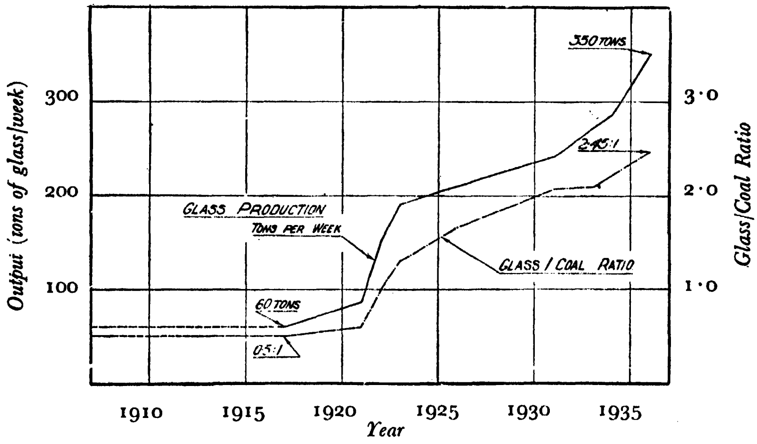

FIG. 9.—Increase in output of a tank furnace melting bottle glass.

TABLE I

IMPROVEMENT IN RATE OF MELTING OF A TANK FURNACE MELTING COLOURLESS GLASS

Year	Average melting rate (sq. ft. per ton per day)	Temp. ° C.
1919	16·8	1,350
1921	17·4	—
1923	15·7	—
1927	13·3	—
1929	12·1	1,420
1931	10·1	—
1933	8·6	—
1935	8·2	1,480
1937	7·2	1,510

Whereas thirty years ago the area required to melt satisfactorily one ton of glass per 24 hours was at least 20 sq. ft., today it has been reduced to the order of 8–10 sq. ft. for colourless glass, and 6–8 sq. ft. for coloured glass. Therefore, so far as efficiency of melting is concerned, the changes have been very considerable.

2. REASONS FOR IMPROVEMENT

It is of interest to enquire how this remarkable improvement has come about. The causes of improvement relevant to the discussion of this paper can be divided into three sections, namely, changes of methods of manufacture, changes in furnace design and changes in operation.

With regard to the *method of manufacture*, the use of fully automatic machines which remove the glass so much more quickly than is possible by hand or some semi-automatic machines has been a very important factor in bringing about the enormous advance in production capacity obtained from a given glass tank furnace. To quote an example given by W. E. S. Turner,[3] the "Westlake" machine can produce 70,000 to 100,000 standard electric light bulbs per day, whereas the average production of a skilled glass-blower is from 900 to 1,100 per eight hour shift each day. The influence of the machine has, of course, greatly modified the organisation within the factory and has necessitated the continuous operation of glass tank furnaces for 24 hours for seven days a week for many months and often years on end. This continuous removal of glass from a furnace, assisted by greatly improved methods of batch mixing and charging (see below), has naturally increased its output.

With regard to *improvements in furnace design*, a number of changes have been made, each one by itself of comparatively minor importance, but in their sum total contributing considerably to the better working of the furnace. Such improvements include better port design to ensure the more efficient mixing of gas and air, resulting in a more complete combustion within the furnace proper and thus achieving considerably higher temperatures ; improvements in the flow of gas such as the removal of sharp angles in flues, ports, stack, etc. ; the more efficient design of regenerators and recuperators so as to provide adequate capacity, sufficient height and ample space above and below the checker work and to allow an even distribution of gases ; the very much more extensive use of insulation, gradually extending in the course of years from flues, regenerator chambers and uptakes, to the walls and crown of the working chamber of the tank, and now finally to the crown of the melting chamber ; and the use of much improved refractory materials in every part of the furnace structure.

Annealing furnaces have likewise been improved out of all recognition compared with 20–25 years ago, in regard to simplicity of design, speed of operation and low fuel consumption. Modern lehrs are well insulated and the heat in the glass is generally sufficient to maintain the temperature required in the annealing zone ; therefore, only little external heat needs to be applied. In one factory it has been found that a ton of bottles can be annealed for a fuel expenditure of 6*d*.

The better *operation* of glass melting furnaces and of producers has been brought about to a large extent by improved instrumentation. The installation of essential instruments and the training of operators to work such instruments intelligently has made it possible to avoid fluctuations in operating conditions such as temperature, pressure, glass level, etc.

III. FUEL EFFICIENCY IN THE GLASS INDUSTRY DURING THE LAST FIVE YEARS

Towards the end of 1941 the Society of Glass Technology, together with the Glass Delegacy of Sheffield University, set up a Fuel Efficiency Sub-Committee to deal with all technical matters concerned with fostering fuel economy.

The sub-committee has been responsible for an exchange of views and experiences between its member firms about the efficient use of various types of fuel and the outcome of any experiments which have resulted in increased fuel efficiency. In particular the work of the sub-committee has been concerned with :—

(1) The appointment of a panel of lecturers, chosen to cover all the principal glass-making centres in this country. The members of the panel are technical men with wide experience of fuel and furnace problems. The functions of this panel are to promote lectures to glass-works personnel on the operation of glass-melting furnaces and the most efficient methods of running them ; to train individual operators of boilers, producers and furnaces ; to report to the committee at regular intervals on the progress made in their particular organisation or area in the fuel efficiency drive and to make suggestions for further improvements. Various members of the panel are also serving in an honorary capacity on investigating panels, set up by the Regional Fuel Efficiency Committee of the Ministry of Fuel and Power.

(2) The preparation and circulation of a comprehensive course of lecture notes, for the use of the panel of lecturers, on all subjects relating to fuel efficiency in glass-works practice (fuels, combustion, melting furnaces, use of instruments, boilers, etc.).

(3) The publication of a " Fuel Efficiency Supplement " containing articles and papers of direct and practical interest to technical men in charge of the utilisation of fuel. Particular attention has been paid to the following subjects : thermal insulation, waste-heat recovery, the quality of producer coal, the use of low-grade fuels, efficient operation and sound design of gas producers and furnaces, instrumentation, and assessment of the thermal performance of tank furnaces. Copies of this publication are sent not only to member firms, but to all firms in this country using fuel for the making or treatment of glass.

(4) The issue, at regular intervals, to all firms making glass, of questionnaires for the assessment of the standard of fuel and furnace efficiency. The thermal performance of each of the furnaces for which data were received was calculated and the results communicated to the firms concerned. When desirable, suggestions were offered for raising the standard of performance.

(5) The distribution to members of the panel of lecturers of all technical publications issued by the Fuel Efficiency Committee of the Ministry of Fuel and Power.

(6) The preparation of an account on " Furnaces and Furnace Control in the Glass Industry " for the text-book " The Efficient Use of Fuel," prepared by the Fuel Efficiency Committee of the Ministry of Fuel and Power.

(7) An investigation to correlate the results of laboratory tests on coal with the actual behaviour of such coal in gas producers, and the preparation of a scheme of analysis of producer coal with special reference to wartime fuels.

As a result of the committee's efforts to date a general improvement in the efficiency with which fuel has been used has taken place. The lectures and individual talks with furnacemen have created considerable interest and resulted directly in a substantial reduction of fuel used. The amount of fuel actually saved per unit of output has varied in individual works from something like 5 to 40 per cent., depending very largely upon the *initial* efficiency of each factory.

IV. LINES OF FURTHER PROGRESS

There are clearly two ways in which further advances in the efficient utilisation of fuel may be made, namely, either by revolutionary or by evolutionary methods. In other words, improvements may result either from gradual development of an existing process or by some fundamental change. The British glass industry is quite alive to both methods which will be considered in the following pages.

A. POSSIBILITY OF FUNDAMENTAL CHANGES

1. *Furnace Design*

It is fully realised that in a modern tank furnace a very large proportion of the heat input is required for keeping the furnace itself at the necessary temperature owing to the large heat losses from such a structure.

This is a phenomenon which is, of course, typical of most high-temperature processes. There is, however, an additional feature in glass making which necessitates a large structure for the process of melting, namely, the fact that the physical and chemical reactions taking place during melting are inherently slow processes. This means that the dead weight capacity of a furnace generally has to be at least two to three times that of the actual volume of glass drawn from the furnace per 24 hours.

Attempts have been made within the past 25 years to avoid such a large structure and substitute for the present melting chamber a relatively small, compact one. Two such proposals are worth reporting here :—The first is the Ferguson Shaft Furnace[4] described by the author and tried out on an experimental scale by a British glass manufacturing firm.[5] The process briefly consists in charging the batch mixture into a high-temperature and a high-velocity flame. The mixture is then entrained by the turbulence of the flame and projected upon the walls of the shaft, along the length of which it descends in about half-an-hour. The thermal efficiency of this process has been estimated to be of the order of 60 per cent. However, attempts to translate the experimental work into a large-scale process have so far been defeated owing to construction difficulties and the failure of the refractory material used as lining for the shaft.

An alternative scheme proposed by G. Zotos[6] consists essentially of a hollow cylinder rotated about its long axis at such a speed (60–100 r.p.m.) that the sintered batch and melting glass are spread evenly over the inner walls of the tube, thus leaving a free central passage for the flame. The combustion chamber is thus uniformly enveloped by a thick layer of melting glass which is evenly heated and at the same time protects the lining from contact with the flame. It is also claimed that the corrosive action of the melting batch on the refractory lining is much reduced owing to the fact that there is hardly any motion of the charge relative to the furnace tube.

This process, too, has not as yet been put into practice owing chiefly to mechanical difficulties in construction and operation.

2. *Furnace Heating*

(*a*) *Electric Melting of Glass.*—A considerable amount of effort has been expended on heating glass furnaces by electric methods. Three different processes have been tried, namely, the use of an electric arc, indirect resistance heating and direct resistance heating. Of these three methods only the third one had proved to be practical. The glass itself is used as a resistance in an electrical circuit owing to the fact that glass in its molten state becomes an electrical conductor. The attraction of this process lies in the fact that heat is generated within the body of the molten glass and not outside it, as in all other orthodox methods of heating. Electric melting thus allows a considerable reduction in structural space and a consequent reduction in heat losses.

The first large-scale experiment made in this country was carried out in St. Helens, Lancashire, between 1926 and 1929, on the basis of the Cornelius process.[1]

A full account of this work has been given by E. Meigh[8] in a paper entitled "The Future of Glass Melting." The rate of glass produced to electricity consumed was 1·2 kg. of glass per 1 kWh. Meigh concluded from these experiments that the electric furnace was a sound economical proposition only if electricity was available at the rate of 5 units a penny.

As is to be expected, electric melting on a large and continuous scale has so far been confined to those countries where electric power is cheap as compared with other types of fuel, such as the Scandinavian countries, Switzerland and certain parts of the United States. For example, Y. R. Cornelius[9] described a large-scale electric glass-melting furnace built at the Niagara Falls, in which the power consumption was 1 kWh per 1·12 kg. of glass melted. The process was continuously operated for fifteen months and the rate of production was one ton of glass per 6 sq. ft. of melting area per 24 hours.

A cross-section of the furnace used is given in Fig. 10. The electrodes are situated on two platforms running along the side walls of the furnace, such that the top surface of the electrodes just reaches the sintered batch. A batch blanket covers the whole melting area and acts as insulation to the heat generated

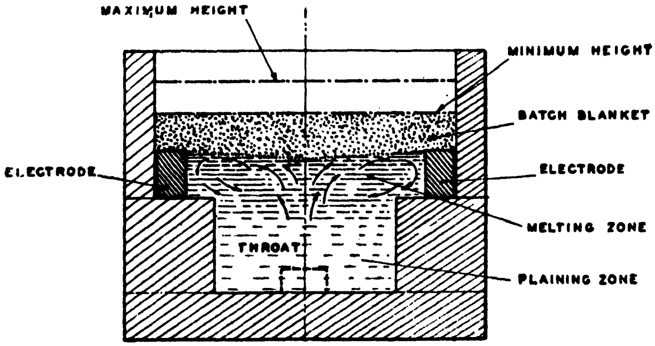

FIG. 10.—Cross-section through electric furnace for melting glass.

within the glass. The minimum batch thickness suggested is 14½ in. and it may be increased by 12 in., depending on the rate of production required.

Whilst it is obvious that electric melting gives considerably higher glass-melting efficiency, two factors must be borne in mind. First, that in considering the overall efficiency of the process, the efficiency of the power station must be taken into account and, secondly, that, unless the price of electric power in this country can be very substantially reduced, electricity as a " fuel " for glass melting, although very attractive technically, cannot compete with gaseous and liquid fuels.

(*b*) *High Intensity Burner.*—There remains the question whether gaseous and liquid fuels can be burnt in a more efficient manner. One such method that appears promising utilises the principle of surface combustion. According to information which R. J. Sarjant[10] has kindly provided, a high-intensity burner developed in the United States was claimed to have the phenomenal rate of heat release of 60,000,000 B.Th.U./cu. ft./hour. Dr. Sarjant has also drawn our attention to a paper entitled " The Concentrated Combustion Burner ", by J. Palser.[11]

The Glass Industry Fuel Efficiency Committee is at present giving attention to this method and its possible application to glass melting. It may be stated, however, that development along those lines has been proceeding for some time in certain sections of the glass industry, in which it is essential for oxidising conditions to be maintained throughout the melting process.

B. EVOLUTIONARY METHODS OF PROGRESS

Summarising the present state of development of revolutionary or fundamental changes it can be said that within the next few years no outstanding measure of fuel saving is to be expected which would affect the fuel consumption of the glass industry as a whole. It is as well to recognise that furnaces using producer gas have undergone very little change in fundamental design.

It is by the evolutionary process that great progress in fuel economy in the glass industry has been made during the past 25 years, improvements in general having been achieved by closer attention to detail. It is probable that further progress—at any rate in the near future—is likely to be made on similar lines. In the following pages a review will, therefore, be given of the possibilities of further progress by the gradual improvements in the design, control and operation of glass-melting furnaces.

1. *Improvements in Furnace Design*

(*a*) *Counter-flow Furnace.*—An interesting design of a counter-flow furnace has been proposed by W. A. Moorshead.[12] Combustion takes place only in that part of the furnace which is required to be at the hottest temperature, namely, in the so-called refining chamber. After combustion has been completed the hot gases enter the comparatively long and narrow melting section of the furnace, where the heat of the outgoing gases is utilised for melting the incoming batch materials. In this way the outgoing gases leave at a much lower temperature than is the case with the normal type of furnace.

(*b*) *Cross-fired versus End-fired Furnaces.*—It is generally assumed that end firing, i.e. ports in the end wall of the furnace with a " U " flame passing along the length of the furnace, is only applicable to comparatively small furnaces. Thus, F. G. Schwalbe[13] asserts that end firing is not an efficient proposition when applied to furnaces with melting areas greater than 300 sq. ft. On the other hand, an end-fired furnace known to the writer, which has a melting area of 600 sq. ft., is recognised to be one of the most efficient glass-melting furnaces in the country.

End firing has the great advantage of allowing longer length of flame path and thus avoids incomplete combustion. As W. A. Moorshead has pointed out,[3] the greatest difficulty with the end firing of furnaces is to make provision for large enough ports. But there appears to be no reason why this condition should not be fulfilled and it may well be worth while to give further consideration in the future to the advantages of end firing, particularly in view of the fact that the majority of furnaces in this country do not exceed a melting area of 500–600 sq. ft.

(*c*) *Port Design.*—The correct design of ports is of fundamental importance for obtaining complete combustion, particularly in cross-fired furnaces. The particular design of a port which will give the best results will have to be decided for each individual furnace by carrying out the necessary measurements, such as gas analyses in the exit ports and the observations of flame length for each separate port. However, as an illustration of what may be done in a particular case, it may be of interest to mention the following modifications to port design, reported by W. A. Moorshead.[14]

(i) Alteration of the gas flow so as to meet the air perpendicularly ;

(ii) Increasing the velocity of the gas relative to the air.

Another factor which has to be considered in connection with port design is the proportion of the melting area covered by the flames issuing from the ports. R. S. Arrandale[15] recommended that, expressed as a percentage of the melting end area, the total " port coverage " on the surface of the glass should be about 40 per cent.

(*d*) *Combustion Space.*—In order to reduce heat losses from the furnace structure the size of the combustion space should be reduced to the minimum required for a given port design and rate of melting.

There is little doubt that in a number of furnaces the size of the combustion space could be reduced and fuel saved if the port design was such as to give the best possible mixing of gas and air.

On the other hand, it may be of interest to recall a recent article[16] entitled " Operators Want More Combustion Space in Glass Tanks ". It was pointed out that owing to faster operating conditions, i.e. increased output per sq. ft. of furnace area, it had been found that an increase in combustion space was required.

(*e*) *Optimum Furnace Size for a given Output and a given Melting Temperature.*—The remarks made above about the size of the combustion space apply with equal force to the size of the furnace as a whole. For a given required output the size should be as small as is consistent with the production of glass of *good* quality. In actual practice, however, the output required from a given furnace is not constant. It varies with the size of the article being made and with the requirements of the sales department. Consequently, in designing a furnace a certain margin is generally allowed so as to cope with peak loads which may be required from time to time.

Such an arrangement is obviously uneconomical from the point of view of fuel consumption and, whilst a certain margin must be provided, it is in many cases too generous. As a result, many furnaces are larger than is necessary during, say, nine-tenths of the life of the furnace. The writer knows[17] of at least three cases in which savings of 25 per cent., 25 per cent. and 7 per cent. respectively were made by reducing the length of the furnace. In the first case one of the four ports on each side was eliminated, in the other two cases two of the three ports on each side were moved so that the three ports were all closer together. W. A. Moorshead[18] has shown graphically the relation between furnace size and fuel consumption and has estimated that in many cases it would be possible to bring about a reduction in furnace size equivalent to 6 to 9 sq. ft. per ton of glass for 24 hours. For example, a furnace with an output of 25 tons per day would require 20 per cent. less fuel if its size were reduced from 500 sq. ft. to 300 sq. ft.

(*f*) *The Relation between Length and Width of a Tank Furnace.*—No definite relationship is known to exist between the length and width of a tank furnace. For nine regenerative tank furnaces considered by the Furnace Committee of the Society of Glass Technology[19] the ratio of length to width varied from 1·01 to 1·90. From information published by R. S. Arrandale[20] for five American tank furnaces this ratio varied from 1·6 to 2·3.

Arrandale condemned an oil-fired furnace 16 ft. wide as far too narrow. Even a width of 18 ft. was found inadequate when a producer-gas fired furnace was operated at its maximum possible output.

Clearly, the ratio of width to length depends on the port design, on the melting rate and on the type of fuel used ; a great deal may be said in favour of shorter and wider furnaces although each case must be examined on its own merits. Such examinations may in a number of cases lead to considerable economies.

(*g*) *Relation between Furnace Size and Fuel Consumption per Square Foot of Heated Glass Surface.*—There is, however, another aspect of furnace size which has a direct bearing on fuel saving, namely, the fact that large furnaces operating under comparable conditions require less heat per sq. ft. of molten glass surface than do small furnaces. A quantitative expression of this relation was derived by W. M. Hampton[21] on theoretical grounds, and in the United States by F. G. Schwalbe[22] on the basis of actual measurements. There is remarkably close agreement between the two sets of values ; those of Schwalbe are shown in Fig. 11.

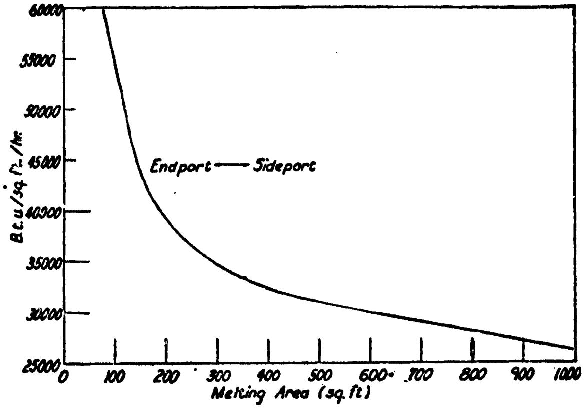

FIG. 11.—Relation between size of melting area and fuel consumption required per sq. ft. of melting area per hour.

Further—as yet unpublished—calculations bearing on this point have recently been made by C. E. Gould.[23] Assuming a constant melting temperature of 1,400° C., a constant melting rate of 10 sq. ft. of total furnace area per ton of glass per 24 hours and the same efficiency of furnace design and operation, the following data were derived :—

TABLE II

EFFECT OF FURNACE SIZE ON EFFICIENCY

Area sq. ft.	Tons of coal per ton of glass	Percentage thermal efficiency[24]
40	0·76	7·9
60	0·66	9·1
80	0·60	10·0
100	0·56	10·6
200	0·46	13·0
300	0·42	14·2
400	0·39	15·2
500	0·37	16·0
600	0·36	16·5
800	0·34	17·4
1,000	0·33	18·0
1,500	0·31	19·2
2,000	0·30	19·9

It thus follows that as the size of the furnace is increased, the coal/glass ratio progressively decreases and the thermal efficiency correspondingly increases. From these data it is obvious that one comparatively large furnace is more economical from the point of view of fuel consumption than a series of smaller furnaces.

(*h*) *Improved Methods of Charging the Batch.*—It is generally agreed that the slagging of regenerators and recuperators is one of the greatest obstacles to the better design of a waste-heat recovery system. The choking of regenerators and recuperators is largely due to the " carry-over " of batch dust and it may well be that further improvements in waste-heat recovery will depend to a large extent on improved methods of batch feeding.

Two such methods are available and have been used, particularly in the United States. The first method consists of " blanket feeding ". The batch is charged continuously in a thin layer over the entire width of the melting section of the furnace and the carry-over of batch dust is considerably reduced. The second method consists of charging the batch in the form of briquettes, thus eliminating batch dust altogether. F. G. Schwalbe[25] recently attributed the excellent performance of a furnace, which ran satisfactorily for 1,340 days without any shut down for resetting of the checker work, largely to the use of briquetted batch.

2. *The Application of Insulation and Cooling to a Melting Furnace*

Considerable progress has been made in the glass industry in the application of insulation to those parts of the furnace which had hitherto been regarded as unsafe for insulation. This applies particularly to the crown of the furnace, to the uptakes and ports, as well as, in the case of furnaces melting coloured glasses, to the lower sections of the side walls and to the bottom.

The Fuel Efficiency Committee of the Glass Industry is satisfied that the insulation of a crown is now an entirely practical proposition and will effect direct fuel saving of 12 to 15 per cent. To the committee's knowledge the crowns of quite a number of tank furnaces have been completely and successfully insulated. The method used in almost every case has been the one recommended by the Committee and shown diagrammatically in Figs. 12 and 13.

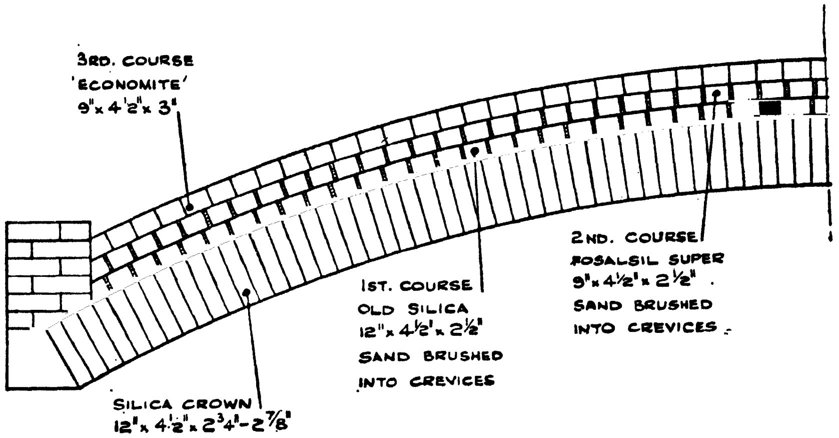

FIG. 12.—Application of insulation to furnace crown.

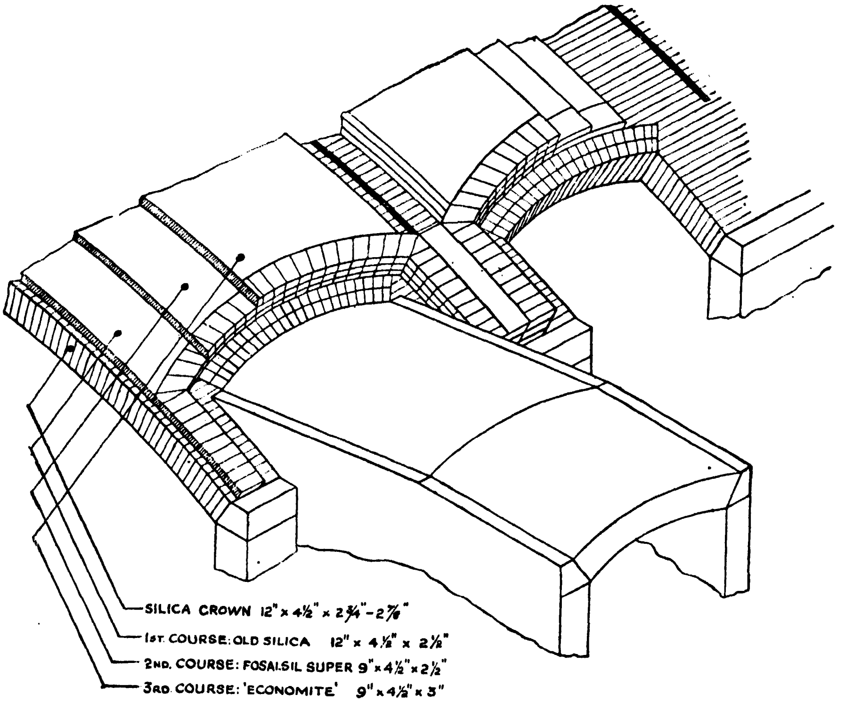
SILICA CROWN 12"x 4½"x 2¾"-2⅞"
1ST. COURSE: OLD SILICA 12" x 4½" x 2½"
2ND. COURSE: FOSALSIL SUPER 9"x 4½"x 2½"
3RD. COURSE: 'ECONOMITE' 9"x 4½"x 3"

FIG. 13.—Application of insulation to furnace crown.

A parallel development to the widespread use of crown insulation has been the more judicious application of cooling. The latter is normally applied with the object of lowering the temperature of the inside surface of the tank blocks, particularly at the glass level and thereby reducing the corrosive action of batch and molten glass on the refractory walls. It has been estimated[26] that the heat removed from the side walls by cooling is of the order of 15 per cent. of the total heat input. It is, therefore, important to note the view expressed by W. M. Hampton,[27] namely, that the cooling of tank walls is of no value in the early stages of the life of a furnace. There are furnaces which have cooling applied only after the tank blocks have been considerably reduced in thickness by corrosion. Since this reduction in thickness does not occur until the furnace is approximately in the last third of its campaign, considerable saving of fuel can be achieved by such deferment of cooling. The precise effect of cooling on the rate of wear of tank blocks and on the thermal performance of the furnace as a whole is being studied at present by the Furnace Committee of the Society of Glass Technology.

It must also be borne in mind that effective cooling is expensive. Investigations are proceeding to determine the economics of cooling in an endeavour to find out what increase in furnace life is necessary to make cooling pay. From some preliminary information reported by W. M. Hampton and E. Seddon[28] it appears that a minimum increase of 20 per cent. in the life of the furnace is required to make even moderate cooling an economic proposition. For more drastic cooling (4–6 in.w.g.) the increase in furnace life will have to be considerably higher and may amount to 100 per cent.

A determination of the economics of cooling for each individual furnace may well lead to a reconsideration of conventional methods and thus save fuel.

3. *Improved Efficiency of Heat Return*

(*a*) *Regenerators and Recuperators.*—There is no doubt that very substantial savings can be achieved by improvements in the efficiency of heat return as shown in Figs. 14 and 15, prepared by W. A. Moorshead.[29]

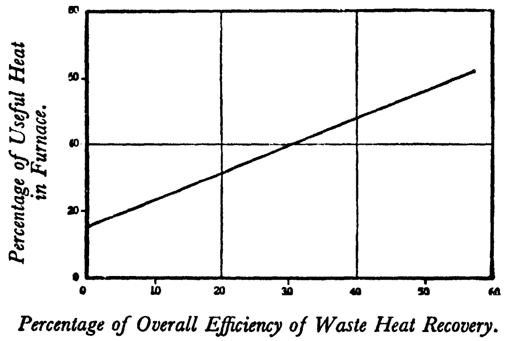

FIG. 14.—Relationship between efficiency of heat return and useful heat in the furnace.

Fig. 14 indicates how the percentage of heat available in the furnace increases rapidly with the efficiency of heat return. If the latter is 30 per cent., the useful heat in the furnace is 40 per cent., but as the efficiency of heat return is raised to 50 per cent., the useful heat in the furnace is increased to 56 per cent. This increase in efficiency means that the fuel consumption is dropped to 70 per cent. of that required for the lower heat return. In Fig. 15 the actual tonnage of coal saved per week for a furnace of given size is shown for efficiencies of heat return of 30 per cent., 40 per cent. and 50 per cent. respectively. For example, taking a furnace with a total glass surface area of 500 sq. ft., it is possible to save 33 tons of coal per week by increasing the efficiency of heat return from 30 per cent. to 40 per cent., and to save 46 tons of coal per week if that efficiency is increased from 30 per cent. to 50 per cent.

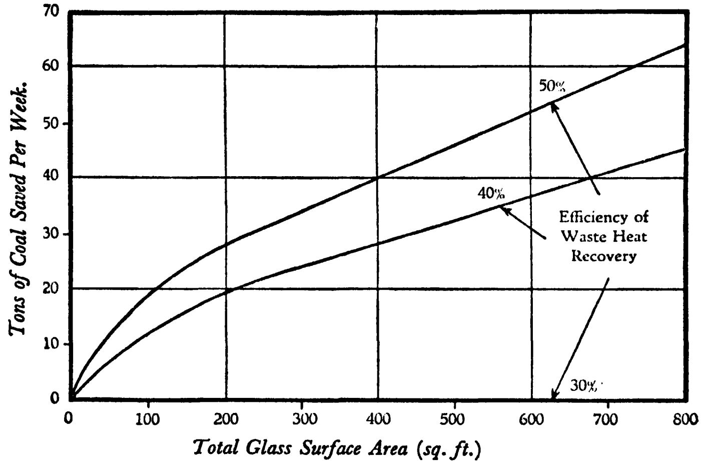

FIG. 15.—Relationship between efficiency of heat return and tons of coal saved per week.

The best methods for achieving efficient heat return in the glass container industry have only recently been fully discussed by W. A. Moorshead[30] in a contribution to the series on "Industrial Waste Heat Recovery", arranged by the Institute of Fuel. It will, therefore, suffice to reiterate a few of the salient points :—

(i) Adequate capacity of regenerators and recuperators. From a questionnaire which the Furnace Committee of the Society of Glass Technology issued some years ago,[31] W. M. Hampton[32] has recently deduced that there is a probability that an increase in the capacity of the regenerators relative to the rate of coal consumption would give better thermal performance value for the majority of furnaces.

(ii) Ample height in relation to cross-section ; for a given regenerator capacity the height should be as great as possible.

(iii) For a given height of regenerators, sufficient space should be allowed below and above the checker work to permit an even distribution of gases throughout the packing.

(iv) A large enough opening at the entrance of the hot gases into the regenerator.

(v) Straight packing with passages of 3½ in. to 5 in. square.

(vi) Refractories of adequate quality for the checker work.

(vii) Forced draught in preheating systems where natural draught is inadequate.

(viii) Increased facilities for inspection and cleaning of the waste-gas passages, but taking care after the completion of the job to have all stoppers and openings well sealed again to avoid air infiltration.

(ix) Better understanding of the relative importance of convection and radiation, of gas velocity and of uniform gas distribution.

(x) Using methods of *calculation* such as those proposed by W. A. Moorshead[3] rather than rule of thumb for arriving at the correct checker volume for a given size of furnace, a given output and a given type of fuel.

(xi) Further investigation of the possible use of metallic recuperators. The absence of leakage in such recuperators may be of sufficient advantage to counter-balance the extra cost of more expensive metals, provided the latter possess adequate resistance to oxidation and the necessary mechanical strength at high temperatures. The installation of complete thermostatic control to avoid exceeding the maximum permissible temperature would seem highly desirable.

(*b*) *Waste Heat Boilers.*—Considerable attention has been paid by the Fuel Efficiency Committee of the Glass Industry to the problem of waste-heat boilers and a large amount of information[33] on the subject has been circulated to all member firms. It must be borne in mind, however, that the problem is not a new one as far as the Glass Industry is concerned. Almost 20 years ago W. E. S. Turner[34] drew attention to two installations of waste-heat boilers which were recovering 8·2 and 12 per cent. respectively of the heat input.

Similar figures have quite recently been given by E. Seddon[35] who calculated that the heat lost to the stack without a waste-heat boiler was 20 B.Th.U./n.cu. ft., but only 8 B.Th.U./n.cu. ft. when a waste-heat boiler was installed. W. A. Moorshead, in his paper on " Waste Heat Recovery in the Glass Container Industry ",[3] expressed and substantiated the view that " the case for the use of waste-heat boilers on glass-melting furnaces appears to be overwhelming " and showed that the introduction of a waste-heat boiler increases the overall efficiency of a good glass-melting furnace from 19 to 34 per cent.

Yet it must be admitted that the number of waste-heat boilers operated successfully in connection with glass melting is still comparatively small and the question naturally arises why this should be so. Since both the above-mentioned authors have discussed this problem very fully, it will suffice to summarise here the chief difficulties which have been given as standing in the way of the more extensive use of waste-heat boilers and to state the possible remedies which have been suggested. This has been done in Table III.

TABLE III

WASTE-HEAT BOILERS USED IN GLASS WORKS

Possible difficulties and suggested remedies

Possible difficulties	Suggested remedies
(1) More steam produced by waste-heat boiler than used in producers.	Use of surplus steam for engines, hot water, process work—in one case even for glass blowing.
(2) Temperature of waste gas at bottom of regenerators below 500° C.	(*a*) Insulation of regenerators. (*b*) Modification of checker packing.
(3) Appreciable distance between foot of regenerator and entrance to waste-heat boiler.	Effective insulation of flues.
(4) Acid and tar deposition caused by too low an outlet temperature from the boiler.	Reduction of boiler capacity by blocking off some tubes.
(5) Lack of space or other structural difficulties.	Making the necessary alterations when rebuilding the furnace.
(6) Complication in operation of furnace.	(*a*) Increased technical supervision. (*b*) Increased instrumentation.
(7) Unsteady draught conditions due to the choking of the tubes.	Frequent cleaning of tubes.
(8) Leaks in flues.	Greater attention to air infiltration.
(9) Leaks in air-reversing valve.	Use of positive seal valve.
(10) Hardness of water.	Installation of water softening plant.

4. *Improvements in Furnace Control*

The importance of accurate control as a means to fuel economy can hardly be over-emphasised. For example, a reduction in output will lead to an increase in furnace temperature unless the heat input has been correspondingly decreased. Similarly, variations in the calorific value of fuels will require adjustments in the fuel input if uniform conditions are to be maintained and fuel is to be saved.

Such control is only possible if the necessary instruments are available. Apart from such essential instruments as a draught gauge, a portable gas analysis apparatus, an optical pyrometer and a temperature recorder—instruments which few works are likely to lack—the following additional methods of control are now becoming available or are in process of development :

(*a*) The measurement of heat input into a furnace, not only of fuels which readily lend themselves to metering such as clean gases and light fuel oils, but also of hot raw producer gas, creosote/pitch, etc.[36]

(*b*) The metering of the supply of air entering the furnace system. This would give better combustion control and would assist in using a minimum amount of excess air. Suggestions for a rough method of metering have been made.[37]

(*c*) An automatic stack damper control which will maintain a constant pressure inside the combustion space. It has been estimated that no less than 5 per cent. of fuel can be saved by the installation of such equipment.

(*d*) The use of a heat flow meter for determining optimum combustion and heat transfer conditions within a furnace. The Glass Industry is aware[38] that there is considerable scope for the use of such an instrument in exploring a variety of furnace problems.

(*e*) The provision of a glass-level gauge that will continuously indicate and record the glass level in a tank furnace feeding automatic machines.

These few illustrations may serve to indicate that considerable economies can be expected by ever increasing instrumentation, with the proviso, of course, that there is adequate technical staff to maintain the instruments in good working order and to interpret the results intelligently. A final example of the extent to which automatic control has been applied to glass furnaces[39] is given in Fig. 16, which shows how an American oil-fired glass-melting furnace is controlled.

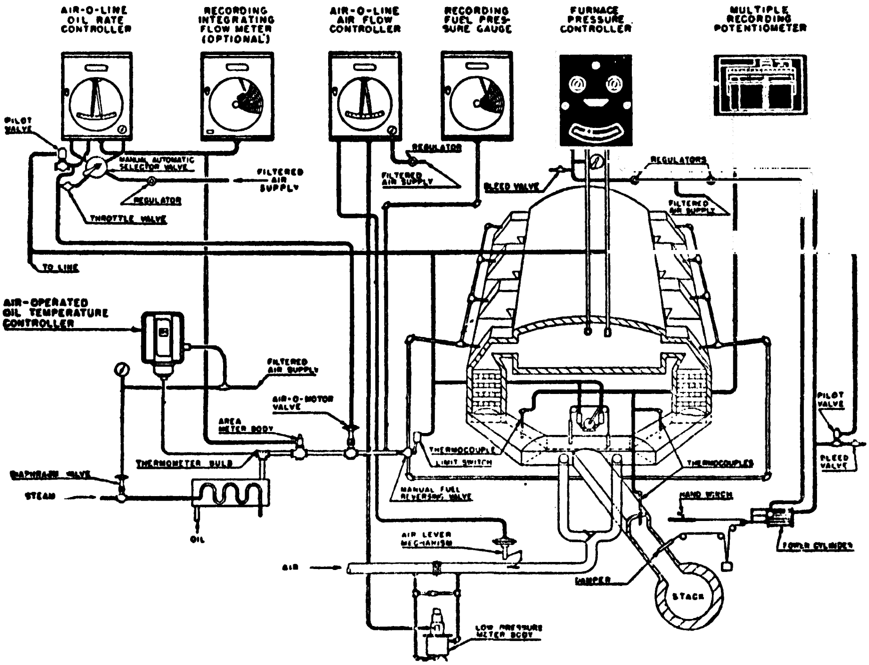

FIG. 16.—Automatic control of an oil-fired glass-melting furnace.

5. *Improvements in Furnace Operation*

A good furnace operator will try continually to improve upon the operation of his furnace. Here are a few hints which may help him in his job :—

(*a*) For a given load the furnace temperature should be reduced until the first appearance of " seedy " glass. The temperature should be just slightly increased until glass of satisfactory quality is obtained. That temperature is the most economical one at which to operate the furnace. W. A. Moorshead[40] reported that in a few cases temperatures have been lowered by 50° C. without detrimental effect on the quality of glass.

(*b*) The supply of air to a furnace by means of forced draught instead of relying on natural draught. Fan air can be controlled and metered, whereas natural draught is variable, since it depends on changes in atmospheric temperature, etc., and is limited to provide a pressure of the order of 0·1 in.w.g. in the combustion space.

(*c*) Pressures in the combustion space up to 0·2 in.w.g. have been used successfully in forced-draught furnaces with the result that there was a noticeable improvement in the thermal performance of the furnace.

(*d*) Equal distribution of gas and air through the various ports. E. J. Gooding and M. W. Thring[41] have shown in a systematic examination of the air flow through a glass tank furnace that gases entering a regenerator do not necessarily distribute themselves equally to all ports. " Spy " holes for the easy observation of the flames entering each port are, therefore, essential. Improved operation would be achieved if the flow of gases through each port were controlled separately by use of dampers in each individual port. This is, in fact, the practice with some glass furnaces, but mechanical difficulties have, so far, prevented a wider use of this method.

(*e*) Greater application of luminous radiation in glass-melting furnaces. The combustion of a luminous flame is more protracted than that of a similar non-luminous flame and, according to R. H. Sherman,[42] results in a more uniform heat distribution over the entire furnace. Moreover, the thermal energy absorbed by the suspended carbon particles and then radiated to the enclosing surfaces may, in many cases, exceed considerably the radiation due to carbon dioxide and water vapour.

According to W. Trinks,[43] the depth of a glass-melting furnace was more fully utilised with a luminous flame with the result that 50 per cent. more good glass could be produced. Further, the colour of the glass at the tank bottom, as observed through the joints of the bottom bricks, was dark for non-luminous, but light for luminous radiation. Similarly, F. G. Schwalbe[44] noted that the introduction of luminous radiation increased the temperature of glass at the tank bottom by 190° F.

No systematic study has yet been made of the effect of luminous radiation on the heat transmission through molten glass. In view of the possibility of increased output per unit of fuel this subject is one to which further research should be devoted.

6. *Increased Output from a Furnace of Given Size*

In a previous section dealing with improving the design of furnaces, consideration was given to the optimum size of a furnace for a given output and a given temperature. Let us now assume that the furnace size is fixed (this is so, in any case, during the furnace life, which for tank furnaces is generally of the order of 18 months to two years) and consider whether fuel economies can be brought about by increases in either output or temperature.

(*a*) *Increased Output from a Furnace of Given Size and Given Melting Temperature.*—It is a well-known fact that fuel efficiency increases with load. It was shown[45] almost 20 years ago that a 10 per cent. increase in load on a glass-melting furnace necessitated a rise in fuel consumption of only 1 per cent. and that when the load was increased by 100 per cent. the fuel consumption went up by 10 per cent. Thus, furnaces should work at the greatest possible capacity, the only limitation being the quality of the glass. In fact, the danger of high production rate *at the expense* of glass homogeneity must be emphasised. The greater the rate of pull on a furnace, the more essential does it become to maintain as careful control as possible of the quality of the glass.

It may not always be possible to plan production so as to allow the furnace to be operated at its maximum load, particularly in view of the large variety of articles of different size, weight and shape produced simultaneously from one furnace. Hence, increased standardisation of ware—a very definite development in the United States where production rates per sq. ft. of area are, on the whole, considerably higher than in this country—would very likely lead to increased production per unit of fuel consumed.

(*b*) *Increased Output from a Furnace of Given Size by Increasing the Melting Temperature.*—There has been a steady increase in melting temperature for a given type of glass. Taking a normal colourless bottle glass composition, the average melting temperature used to be about 1400° C. In recent years this temperature has been increased in most works to 1450° C. and more (*see also* Table I). It is known[46] that in the United States even higher melting temperatures are employed. The average melting temperature for the above-mentioned type of glass would be no less than 1480° C. and may rise to 1550° C., which is the temperature reported " at one factory melting glass *at high speed.*" More recently A. K. Lyle[47] has shown quantitatively how the melting rate of four commercial soda-lime-silica glasses melted in continuous tank furnaces increased as the melting temperature was raised. Melting rates ranged from 4 to 20 tons of glass/100 sq. ft./24 hours for temperatures from 1425° C. to 1570° C.

Two questions arise. Does production *per unit of heat input* increase with increase in temperature ? If so, what is the most economical melting temperature ?

The problem is complicated, since the following factors must be taken into account :—

(i) An increase in melting temperature, for a given quality of refractory material, will increase corrosion and reduce the life of the furnace.[48]

(ii) The use of better quality refractory materials, essential at higher melting temperature and for increased rates of melting, will increase costs.

(iii) There must be facilities for additional machines to be grouped round the furnace.

(iv) The requirements of the Sales Department at any particular time.

With regard to the first question put above, the writer is indebted to W. M. Hampton[49] for some interesting data. For a furnace of given melting area (*i.e.* 570 sq. ft.), given quality of refractory material,[50] given type of glass (*i.e.* a soda-lime-silica glass) and given thermal performance[51] (*i.e.* 5 B.Th.U./sq. ft./sec.), there is a marked decrease in the coal/glass ratio with increase in temperature as shown in Table IV.

TABLE IV

RELATION BETWEEN MELTING TEMPERATURE AND COAL/GLASS RATIO

Temp. ° C.	Sq. ft./ton/day	Production/ 24 hours	Coal consumption/ 24 hours	Coal/glass ratio
1350	28·1	20·3	11·7	0·58
1400	18·0	31·7	14·0	0·44
1450	11·4	50·0	17·3	0·35
1500	7·5	76·0	22·0	0·29
1550	5·1	111·8	29·2	0·26
1600	3·6	158·2	38·5	0·24

With regard to the second question as to the most *economical* melting temperature, Hampton has made some calculations of the true melting cost, which includes the cost of coal, labour, replacement of worn refractory blocks and interest on the capital involved. For a given glass,[52] a given tank (melting end area 570 sq. ft.) and a given quality of refractory blocks, Hampton has found that the melting cost per lb. of the glass produced falls rapidly as the melting temperature is raised from 1350° C. to 1500° C.

Similar calculations for other conditions can and should be carried out in order to determine the most economical melting temperature for any given furnace, melting a given type of glass.

7. *Improved Methods for Assessing the Thermal Performance of Tank Furnaces*

It has always been recognised that fuel can only be utilised efficiently if it is known as precisely as possible how the available energy is distributed throughout the system. One of the first complete heat balances for a glass-melting furnace was drawn up in 1910.[53] Since then the use of " Sankey " diagrams has been well established and some examples of heat-flow diagrams for glass tanks have been published in the textbook on " The Efficient Use of Fuel."[54] An illustration of a heat flow diagram for a modern tank furnace[55] is given in Fig. 17.

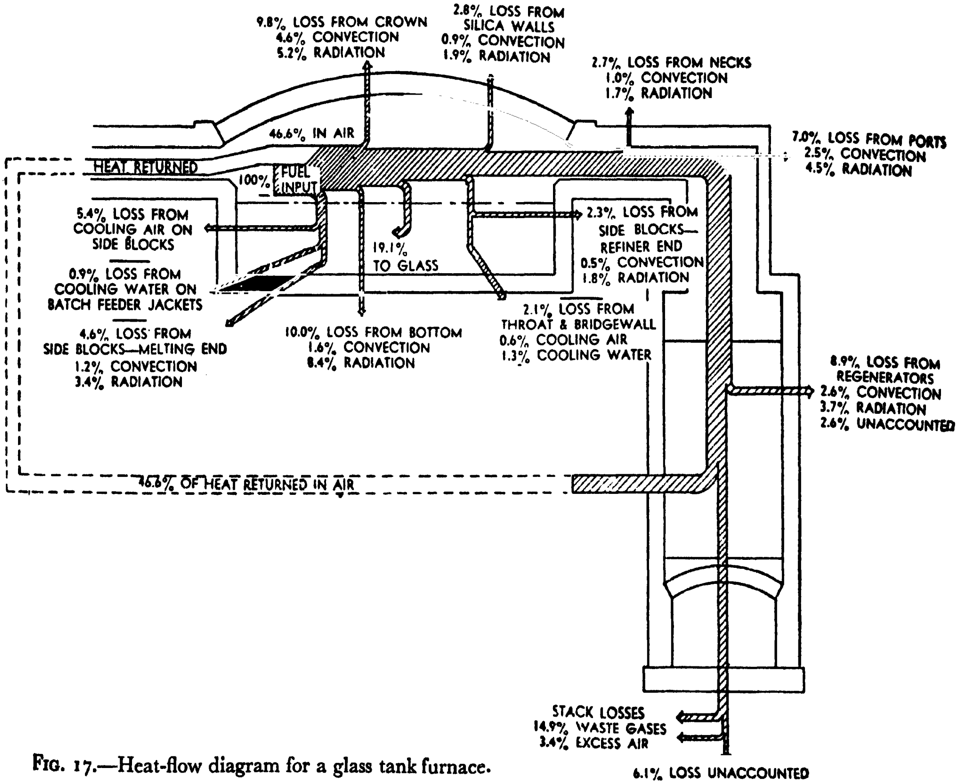

FIG. 17.—Heat-flow diagram for a glass tank furnace.

It must be admitted, however, that heat balances, whilst providing useful information on the distribution of heat losses, do not present a convenient method for comparing the thermal performance of different furnaces. In the first instance, the various items making up the heat balance cannot be determined accurately enough to serve as a basis for comparing the heat distribution of one glass tank furnace with that of another and, secondly, such comparison cannot be accurate unless allowance is made for differences in the melting rates. The same difficulty presents itself when the performance of a furnace is expressed in terms of the weight of fuel used per ton of glass melted. Unless the rate of output is constant, the coal/glass ratio is unsatisfactory as a criterion of furnace performance, since the greater part of the fuel is not used for melting glass, but merely for maintaining the furnace structure at a given temperature.

A great advance was made by the introduction of the " Moorshead Formula "[56] which expressed the performance of tank furnaces for an arbitrary standard load. This method has recently been further extended by the Furnace Committee of the Society of Glass Technology.[57]

The basis of the new method is the realisation that the factors which affect furnace performance may be usefully divided into two classes, *i.e.* imposed factors determined by production requirements and factors associated with the design and operation of the furnace. The purpose of the new method is to allow for imposed factors (rate of output, furnace temperature, furnace size, fuel quality, furnace age, heat transmitting property of the glass) so that the formula gives an expression of the true thermal efficiency of the furnace.

This method of assessing thermal performance has already been well established in the Glass Industry, and is proving invaluable as a convenient yardstick whereby the effect of alterations in furnace design and operation can be measured quantitively. Further important contributions have recently been made by B. P. Dudding[58] who has examined the statistical implications of the data obtained from an application of the new method of assessing furnace performance. As Dudding points out, " if thermal furnace performance is plotted on a chart against limits determined under good normal conditions, attention will be directed to departures from normal conditions early enough to enable technical investigations to be initiated at the time they are most likely to be effective."

As an illustration of the relation between thermal performance and actual fuel saving in terms of tons of coal, F. Winks[59] has prepared the diagram shown in Fig. 18. This nomogram[60] makes it possible to read off directly the tons of coal saved or additionally required per week for a furnace of a given size as the thermal performance falls below or rises above 5 B.Th.U. per sq. ft. of furnace melting area per second.

V. OIL FIRING

It should be pointed out that the use of oil as a fuel in the glass industry is not new. It obtained its greatest impetus during and immediately after the General Strike. In 1928, T. C. Moorshead[61] discussed fully the vexed question of " Fuel Oil versus Coal."

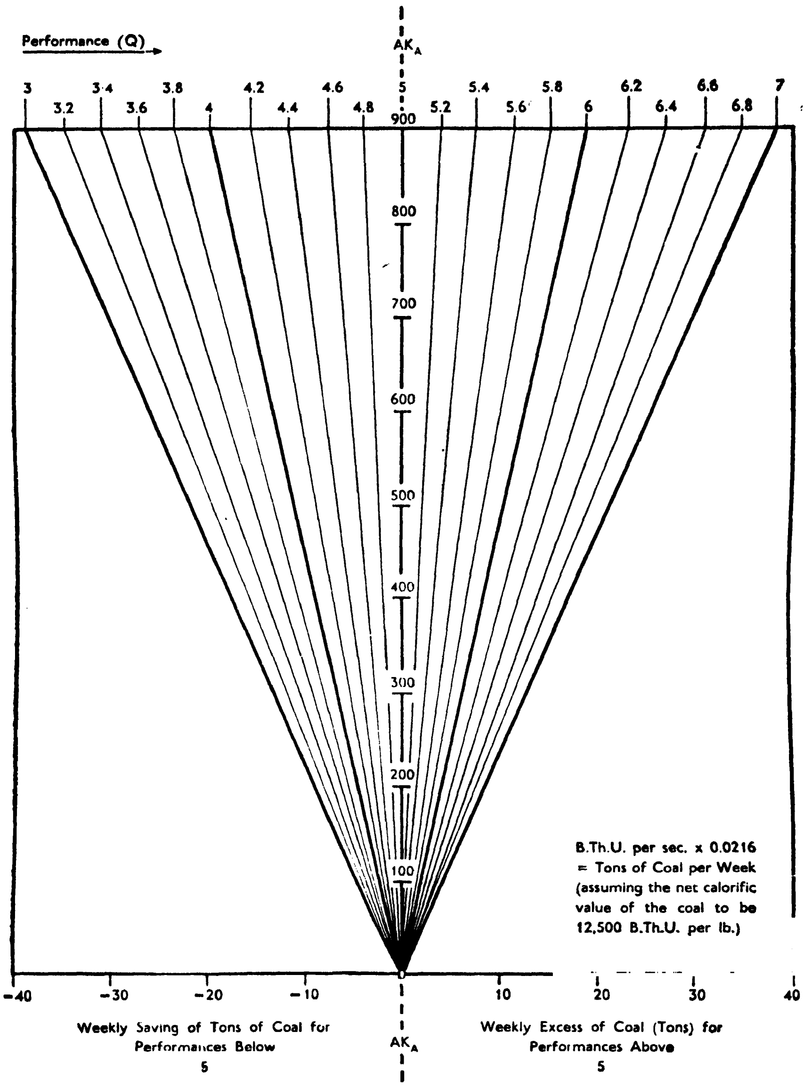

Fig. 18.—Relation between thermal furnace performance and fuel consumption for glass tank furnaces of varying size.

Some of the important points to be borne in mind when considering the use of fuel oil for glass melting are :—

(1) Cost relative to that of other fuels.
(2) Effect on the life of the furnace.
(3) Content of sulphur, ash and water.
(4) Viscosity, specific gravity and flash point.

Since another session of this conference will be devoted to this subject, the following brief remarks will suffice :—

The true cost of oil in comparison with other types of fuel has been fully discussed by W. A. Moorshead.[62] Taking into account the purchase price, labour charges, the cost of auxiliaries (compressed air or steam for atomising, steam for blowing producers, heating and pumping costs for liquid fuels), maintenance of plant, interest on capital and depreciation of plant, Moorshead calculated what the price of other fuels must be to equal the cost of melting by producer gas with coal at, say, 40*s.* per ton. The equivalent prices at which other fuels must be purchased are :—

£4 7*s.* 8*d.* per ton for fuel oil.

£3 13*s.* 7*d.* per ton for creosote/pitch, and 2·65*d.* per therm for coke-oven gas.

As to the life of the furnace, it is well known that an oil flame is much " fiercer " than a producer flame. Consequently, the attack on the refractories of an oil-fired furnace is much more severe and its life is correspondingly reduced, *i.e.* it " ages " at a greater rate than a producer-fired furnace. This effect is clearly shown in Fig. 19, taken from the paper by Moxon, Winks and Dudding.[3] The thermal performance (expressed in B.Th.U./sq. ft./sec.) deteriorates at a much faster rate with oil firing than with producer-gas firing.

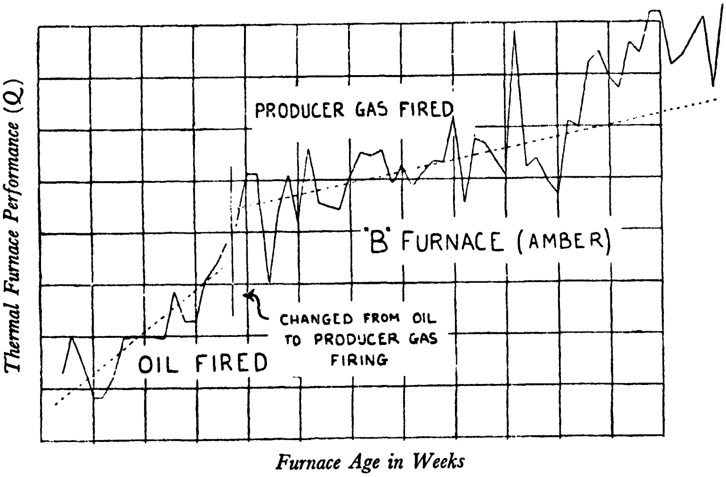

FIG. 19.—The " ageing " of a tank furnace when heated by producer gas and oil respectively.

Finally, with regard to the chemical and physical properties of heavy fuel oils, attention is drawn to the existence of a " Standard Specification for Creosote Fuel Oil for Use in Glass Works," issued by the Society of Glass Technology.[63]

VI. CONCLUSIONS

In summarising the present review, the following conclusions can be drawn :—

(1) A remarkable advance in the rate of melting glass per unit of output has been made in the Glass Industry during the last 30 years.

(2) The fuel efficiency drive during the last five years has resulted in substantial savings varying from 5 to 40 per cent. of fuel per unit of output, according to the initial efficiency of individual works.

(3) It is unlikely that any revolutionary developments will take place within the next few years as far as the design of glass-melting furnaces is concerned. The electric melting of glass, although very attractive technically, cannot at present compete as regards costs with gaseous and liquid fuels.

(4) It should be remembered that it would be false economy to introduce modifications in furnace design or operation which would have a detrimental effect on the quality of glass produced.

(5) Further progress is possible by a systematic study one by one of the factors influencing furnace efficiency. It is certain that fuel can be saved by improved combustion ; the increased application of insulation, particularly to regenerators, recuperators and furnace crowns ; the installation, wherever possible, of a waste-heat boiler ; the employment of the best available refractory materials, thus permitting higher melting temperatures and increased rates of output per unit of fuel ; increased instrumentation and technical supervision.

(6) The savings in fuel that can be made by following the recommendations contained in this paper are appreciable. For example, effective insulation of the furnace crown can save from 12 to 15 per cent. of the total heat input ; the reduction in furnace size without lowering the output has resulted in fuel savings from 7 to 25 per cent.

These and other methods of fuel saving which have been discussed have already—in some cases for years—been applied in many glass works. With an extension of the use of these methods further substantial savings in fuel can be made.

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[33] See e.g., L. E. Norton, " Some Notes on Waste Heat Boilers," *Glass Review, Fuel Efficiency Supplement*, April, 1944, No. **2**, 8–15.

[34] *J. Soc. Glass Tech., Trans.*, 1927, **11**, 318.

[35] Conference organised by the Institute of Fuel in London on 30th April, 1946 ; Official Report, p. 10.

[36] This subject is at present being studied by a Sub-Committee of the Furnace Committee of the Society of Glass Technology.

[37] " *The Efficient Use of Fuel* ", *loc. cit.*, p. 455.

[38] The Glass Delegacy of Sheffield University has been collaborating with the B.C.U.R.A. in developing a suitable instrument and one of the first tests was carried out on a glass-melting furnace.

[39] *Ceramic Data Book*, 1945–1946, p. 349.

[40] *Inst. Fuel War-Time Bull.*, April, 1944, p. 124.

[41] *J. Soc. Glass Tech., Trans.*, 1941, **25**, 21.

[42] *Trans. Amer. Soc. Mech. Eng.*, 1934, **56**, IS-56-1, 177.

[43] *Ind. Eng. Chem.*, 1933, **25**, 865.

[44] *J. Amer. Ceram. Soc.*, 1940, **23**, 173.

[45] E. A. Coad-Pryor, *J. Soc. Glass Tech., Trans.*, 1927, **11**, 325.

[46] W. E. S. Turner, " The North American Glass Industry in 1938 ", *J. Soc. Glass Tech., Trans.*, 1940, **24**, 19.

[47] *J. Amer. Ceram. Soc.*, 1945, **28**, No. 10, 282.

[48] Much attention has been paid to the problem of " ageing " of furnaces, which is considered to be mainly due to the thinning of the side blocks of the tank. It has been clearly shown that there is a steady increase in fuel consumption as the age of the furnace increases. L. Moxon, F. Winks and B. P. Dudding (*J. Soc. Glass Tech., Trans.*, 1944, **28**, 53) have given " ageing factors " for various types of fuel. F. G. Schwalbe (*Glass Ind.*, 1944, **25**, No. 12, 550) reported that a furnace fired by natural gas showed an increase in fuel consumption of 15 per cent. after 13 months, 31 per cent. after 25 months and 49 per cent. after 40 months.

[49] Private communication, dated 5th September, 1946.

[50] This assumption is made to simplify the problem. In actual fact, of course, better refractories would be used at higher temperatures. Indeed, the demand in the glass industry for improved refractory materials is ever increasing, particularly in view of the tendency to use high rates of melting.

[51] An expression of the efficiency of design and operation of the furnace. See *J. Soc. Glass Tech., Trans.*, 1944, **28**, 33.

[52] Lyle (*loc. cit.*) has shown how, for a given melting temperature, the melting rate varies with even slight changes in the chemical composition of the glass. Further research is required to study the precise effect of chemical composition and of " refining " agents on the melting rate.

[53] F. Gelstharp, *Trans. Amer. Ceram. Soc.*, 1910, **12**, 62.

[54] *Loc. cit.*, Chapter XXIX, p. 715.

[55] *Ceramic Data Book*, 1945–1946, p. 342.

[56] *J. Soc. Glass Tech., Trans.*, 1936, **20**, 640.

[57] *J. Soc. Glass Tech., Trans.*, 1944, **28**, 33.

[58] *J. Soc. Glass Tech., Trans.*, 1944, **28**, 63 ; ibid., *Trans.*, Feb., 1946, **30**, 13 ; ibid., *Trans.*, Aug.-Oct., 1946, **30**, 243.

[59] *Glass Review, Fuel Efficiency Supplement*, March, 1946, No. 8, p. 4.

[60] AK_A is the " corrected area " to allow for the fact that, when operating under comparable conditions, large furnaces require less heat per sq. ft. of molten glass surface than do small furnaces. (The relation between actual and corrected area is given in the *J. Soc. Glass Tech., Trans.*, 1944, **28**, 41, Table III.) The factor of 0·0216 shown in the diagram for converting B.Th.U. per sec. to tons of coal per week (calorific value 12,500 B.Th.U. per lb.) is derived as follows :—

$$1 \text{ B.Th.U. per sec.} = \frac{3600 \times 24 \times 7}{2240 \times 12{,}500} = 0{\cdot}0216 \text{ tons/week.}$$

In constructing the diagram no allowance has been made for producer efficiency. Assuming the latter to be 80 per cent., the conversion factor becomes

$$0{\cdot}0216 \times \frac{100}{80} = 0{\cdot}027.$$

[61] *Glass*, 1928, **5**, No. 7, 293.

[62] *Glass Review, Fuel Efficiency Supplement*, March, 1945, No. 6, 1.

[63] *J. Soc. Glass Tech., Proc.*, 1935, **19**, 24.

6. The Scope for Saving in the Smelting and Extraction Side of the Non-ferrous Industry

By STANLEY ROBSON

The diversity of processes and the small size of the units preclude any attempt to make a general review of the subject in the time available. This paper, therefore, discusses some of the problems of the largest fuel consumer of the various non-ferrous metals produced in this country as a typical example.

The extraction side of the non-ferrous metals industry is scantily represented in this country and, while England was formerly the home of the greatest smelting industry of the world, only zinc—of the older non-ferrous metals—has remained in relatively large production, although highly efficient industries for extracting nickel and the light elements have since developed, and copper refining on an important scale still continues. The history of zinc is interesting and can be recorded in terms of fuel saving.

The first production in Europe was in Bristol by a process which became known as the " English process ". The method was described by John Percy in 1861, who recorded that the consumption of coal was 27 tons per ton of metal. This process had then survived nearly one hundred years and was replaced by Silesian and Belgian processes, largely, if not entirely, because they realised a reduction to 11 tons of coal per ton of metal. Step by step these figures were reduced to between 2 and 3 tons of furnace coal per ton of metal by :—

(1) Increasing furnace outputs.

(2) The use of recuperative and regenerative settings.

(3) The substitution of gas producers of ever-increasing efficiency for direct-fired coal grates.

Further improvement was then obtained by improving the grade and physical condition of the metallurgical charge itself, so that by virtue of higher metal content the heat expended in the furnace had less work to do in heating barren materials, and by virtue of the greater reducibility of the material owing to its porous condition, the extraction of the metal proceeded rapidly at lower temperatures than formerly. By these means, the furnace figures were brought down to about two tons of coal per ton metal. From thence, by further increase in retort capacities by improved and mechanical producers, the production in Belgian type furnaces has been brought as low as 1·5 tons in the best examples. A modern horizontal furnace setting will be regenerative—probably in both gas and air—and have mechanical gas producers, and be fitted with waste-heat boilers providing steam for the pottery making the retorts and condensers, used in the process. Nevertheless, the total thermal efficiency, including credit for steam recovered and used, will not greatly exceed 23 per cent. The obvious heat losses from such furnaces arise from the intermittent nature of the process, and possible avenues for further economy lie in still further increasing the reducibility of the charge and its thermal conductivity, and using more heat-conducting materials than clay for the retorts—if such can be obtained at a price the industry can afford. To some extent the two last avenues are related. For example, a great success in the increase of reducibility, or heat conductivity, might permit the temperature to be reduced to the limits at which metal retorts can be used, or, alternatively, research may yield new heat-resisting alloys which can withstand present furnace temperatures over long periods. The first may be realised by the work of a scientist working on the physico-chemical properties of zinc distillation charges; and the second may crown the efforts of some metallurgist who is working on the structure of complex alloys. Success will only be obtained by a fundamental and scientific approach.

Working on immediately obtainable materials and taking full use of available knowledge, the New Jersey Zinc Company of U.S.A., developed a vertical retort furnace process which, as far as furnace coal consumption is concerned, has realised a further major step in fuel economy, and brought the figure down to a net usage of little over 0·6 tons per ton of metal. This figure requires some interpretation because it embodies an economy of about 23 per cent., due to the use of the carbon monoxide which is released by the reduction of the zinc and other oxides in the furnace charge—a procedure which is possible only because the daily production of the retort has risen from about 0·7 cwt. to 100 cwt. The other metallurgical reasons, however, are worth enumeration, and are the replacement of an intermittent process by a continuous one which cuts out dead heat periods, the use of carborundum for the retort wall which improves heat transmission, and the adoption of a briquetting process by which the sintered ore and coal are brought into intimate contact throughout the distillation period, and reducibility thus improved.

The net result is the distillation of 30 lb. of zinc per day per sq. ft. of retort wall, compared with 5 lb. from a horizontal retort. The heat cycle of the whole process is interesting. The producer gas is firstly used to heat the furnace and expel the zinc from the charge, taking advantage of air recuperation ; and secondly, the hot gas leaving the recuperators is used to preheat and coke the charge briquettes which give up all the volatile matter of the reducing coal ; thirdly, this volatile matter is completely burnt and the heat recovered by waste-heat boilers, which produce the steam to drive the fans of the plant and supply the energy for preparing the charge and making the briquettes.

This means a furnace efficiency on the total heat input to the furnace of 52 per cent., *including the value of the steam recovered and used*, and the heat input itself is derived as to 60 per cent. from the furnace coal and 40 per cent. from the coal used for the chemical reduction which is entirely lost in the horizontal process. This is a remarkable achievement and the steps by which it has been attained, while not always reproducible in other smelting processes, are worth applying where possible. Some such heat balance should be made for all furnace operations.

The saving of furnace coal achieved in zinc smelting by vertical and continuous operation, unfortunately, is not complemented by a reduction in reducing coal. Here indeed some sacrifice has had to be made in order to maintain optimum conditions for a high yield of metal, and to avoid retort corrosion and the amount of reducing coal used will depend on the nature of the charge to be distilled, but will be somewhat larger than the 0·65 tons per ton of metal usually employed in the horizontal process.

The scope for saving left to the zinc smelting industry obviously, therefore, lies in the treatment of the retort residues, as part of a charge for another smelting process, or as a means of increasing steam production. There are real and serious problems in all these possibilities at low metal prices, but they have been, and are, the subject of research. In a world of more stable prices than have hitherto been associated with the production of non-ferrous metals, no doubt a successful method—which can be applied within the economy of this country—will be evolved and bring this particular industry to a peak of fuel economy which will be hard to surpass without substantial change in the whole character of the existing processes.

Such is the approach to the problem within one industry, which might be described as the orderly progress of day-to-day improvement. It has yielded handsome results in zinc smelting and copper refining and other smelting operations, and such methods must be applied to all problems. Step by step, the advantages of fuel economy in all these cases have been attained by better use of the total heat of the furnaces by larger unit outputs ; by regeneration ; by recovering waste heat as usable steam ; by improved gas generators, and improved refractories. These are common factors, and the result is possibly more immediately gainful than that attainable by any other means in the same time. This, of course, includes the improvement of the accessory plant and appliances which are to be dealt with in detail in the next sessions, and are the processes by which economies are immediately realisable.

The various processes of the non-ferrous smelting industries present additional problems in the way of realising the best efficiency of ancillary equipment such as boilers, recuperators, economisers and the like on account of the relatively frequent occurrence of fume and dust in sufficient quantity to cause blockages. This has the effect of pre-disposing the use of simple equipment of somewhat lower performance than that which can be attained in other industries. A simple case is use of large regenerator blocks where smaller sizes would improve the heat transfer, and relatively large tubes to permit scavenging where fire-tube boilers are installed. Nevertheless, research brings into light further possibilities by way of process change, which are capable of realising savings which are attainable in no other way. The field of the non-ferrous smelting industry is so diverse that I shall continue to use zinc for a further example.

For years it has been the aim of metallurgists to smelt zinc without using retorts. Obviously, the carbon used for reduction, which must be in excess of the chemical equivalent in order to avoid slagging when retorts are used, might provide the heat for both reduction and distillation in a shaft type of furnace. To do this, it is probable, though not essential, that the residues must be slagged. Heat, therefore, will have to be found for the processes of reduction, of distillation, and of slag smelting—in total a large amount, but nevertheless, a smaller amount than that possible even in a vertical retort process. Complex metallurgical problems will immediately arise in making such far-reaching changes, but, if they can be solved, a further step in fuel economy will be attained. Possibilities of this type occur with the other metals, but are, of course, not likely to affect the fuel position for several years to come. The possibility of substituting oil for coal in non-ferrous smelting operations cannot be dealt with in any general manner. The largest plants which have had their conception and development based on the use of coal can hardly be turned over to oil. Special operations doubtless could in some cases be modified, but operations so complex can only be dealt with in the light of their special circumstances and cannot usefully be described in this short paper.

I would, however, like to refer to a matter of general interest in the smelting of metal. In nearly all cases, of ferrous and non-ferrous metals, heat units have to be supplied at high temperatures. In this field, therefore, the use of oxygen or oxygenated air in place of air alone has always been of theoretical interest.

With the increased importance of fuel economy and the foreseeable development of large-scale oxygen production, we have probably reached a stage where the application of oxygen to industrial processes has become a practical possibility, and indeed success has been claimed in both Russia and Germany in the ferrous field. If this is so, there is no reason why similar progress cannot be made in non-ferrous smelting. The cost of oxygen is a vital factor here. Again, the Russians claim to have made real progress over the Linde-Frankl and Claude methods of oxygen production. That this is possible is to be seen from the present energy consumption of about 0·7 kWh per cubic metre of oxygen which can possibly be reduced to a little over one-half of this amount. The obvious facts are :—

(1) The use of oxygen avoids the furnace heat losses arising from the heating of the large amount of nitrogen present in air. These are substantial where the gas must be vented at high temperatures ; and

(2) The gas from the chemical reactants of the process may be raised in calorific value to something which approaches the value of a water-gas, instead of something less than the value of a producer-gas and this would immensely widen its possible application.

These principles may be applied as circumstances permit to many smelting operations, irrespective of the metal to be extracted, and the scope of saving within such an ambit is wide.

Discussion

Mr. H. C. Armstrong said that greater attention would have to be paid to increasing overall thermal efficiencies. The electric furnace had been cited as a modern appliance of high efficiency, but fuel savings did not result from its extended use because of the low efficiency of conversion of coal to electrical heat. The average furnaces—often little better than boxes—in use in industry were something of which we should be ashamed. For example, Dr. Sarjant had rightly called for good dampers, but dampers had been bad for at least 50 years.

Fuel research in the past had been of little use to industry. No mention appeared to have been made of fuel in the reports of the new iron and steel industry research. The speaker suggested that a research committee be set up consisting of three furnace builders, three fuel engineers, one production manager and one metallurgist, with a non-technical chairman. The essential problem was that of heat transfer, and the committee should have power to spend considerable sums of money and to conduct practical experiments with full-scale furnaces. Experiments on the laboratory scale were of little value. Individual firms could not stand the expense of the proposed research and the Ministry of Fuel and Power was probably the proper authority to instal the necessary plant and to bear full responsibility. The only way to fuel efficiency was to use fuel properly and completely. He urged industry and the Government to " think properly and think big."

Mr. Gardiner agreed with Mr. Armstrong's views but pointed out that new plant could only be installed gradually. Existing knowledge should be translated more speedily into industrial practice. It could not be assumed that everyone was equally willing to pursue higher efficiency and a hard core of resistance must be broken down. The speaker quoted the case of a " large box of bricks ", thermally bad, about which the Directors had decided that something must be done. It was decided to apply burners and recuperation to give 25 per cent. saving, but owing to the danger of the foreman being transferred the whole scheme was dropped and 100,000 cu. ft. of gas per day was still being wasted.

Mr. Thompson thought that a better liaison should exist between management and research departments. Operators were often not trained to maintain efficient working of plant and often newly installed and efficient plant was overlooked and neglected.

Mr. Southern endorsed Mr. Armstrong's view that full scale practical works tests should be made. He distrusted the theoretical views of University students in their industrial infancy and without practical experience. Furnaces designed for high efficiency figures rarely attained 50 per cent. of the designed efficiency in practice owing to the variable conditions obtaining. The starting up and slowing down of a furnace consumed 50 times as much coal as the hourly requirements for maintaining the peak temperature. There was great advantage of three-shift working over two shifts. He considered that considerable savings could be made in the cycle of annealing alloy steel from cold.

Mr. Asquith asked that the Ministry should circulate technical information in view of the difficulties of obtaining such information.

Mr. Brennan pointed out that much of the saving in practice was made by the workmen who use the fuel and it was difficult to obtain their co-operation in the absence of any participation by them in the savings effected. He was sceptical of the value of lectures to stokers.

Dr. Seddon declared that the glass industry was not complacent but that steady evolutionary progress had been made in the past. The industry could not tighten the belt much more. Small savings could only be made by a meticulous examination at every stage of the process, and changes in design could be made only on a long-term policy as a furnace, once lighted, lasted for 1½–3 years and could not be shut down. Suggestions made by the speaker for short term policy were (i) change from producer gas to oil on dual fuel furnaces, (ii) instal insulation on a temporary basis, (iii) pay careful attention to operational factors, and (iv) educate personnel by Ministry of Fuel and Power's classes or preferably by the firm's own technical staff.

For a long-term policy he suggested the need for quantitative assessment of furnace working to assist change in design. He considered that the amount of fuel to be saved was over-estimated.

Mr. Yap Chu Phay preferred the term Conservation of Fuel rather than fuel saving, and called attention to the fact that carbon monoxide was produced in large quantities in the iron and steel industry and was subsequently burned. Best coking coal which was used for this purpose could have been reserved for use in more specialised work as CO could be made from inferior fuels. Inferior coals should be used in all prime movers. The production of cheap oxygen would be an outstanding economy in metallurgical practice. Kapitza in Russia had evolved a process by which oxygen could be produced at a quarter of the cost of the Linde process and it was calculated that the use of a blast of 30–32 per cent. oxygen content would save some 300–400 lb. of coke per ton of pig iron. The use of CO for the direct reduction of iron ore was envisaged.

Mr. L. H. W. Savage wrote : Mr. H. C. Armstrong in his contribution to the discussion on " The Scope for Saving " said that " no mention appeared to have been made of fuel in the reports of the new iron and steel industry research ". If in this connection Mr. Armstrong is referring to the British Iron and Steel Research Association, set up in 1945 to extend the activities of the earlier Industrial Research Council of the Iron and Steel Federation, he is in error, for a Fuel Committee has been appointed, under the chairmanship of Mr. E. T. Judge of Messrs. Dorman Long & Co., Ltd., by the Plant Engineering Divisional Panel. This committee, comprising a number of the most prominent fuel engineers in the iron and steel industry, is surveying the whole field of fuel and power in the industry. It has the power to carry out full-scale field tests whenever necessary, and has already begun work on a number of problems of prior importance.

Dr. Partridge wrote : Furnace efficiency and fuel saving are not necessarily synonymous. The Conference is " Fuel and the Future " and not simply " Fuel Efficiency ". We have heard various estimates of the low thermal efficiencies of high-temperature furnaces ranging from about 8 to 30 per cent. and naturally all of us are anxious to improve them. But this will take time and the immediate savings are likely to be comparatively small because many improvements have already been made.

However, a great deal of fuel might be saved by utilising heat which is now lost. Many of us have seen statements to the effect that the efficiency of a furnace has been increased substantially by the installation of a waste-heat boiler. This is not the case, however. A more correct statement would be that a saving of fuel has been effected if the whole plant be considered as an entity, the heat stored in the waste-heat boiler being used for other purposes. Is not this one method by which a substantial tonnage of coal might be saved ? The waste heat from large plants could be converted into electrical energy and passed into existing distributing networks. Further, should not the Government be advised to supply power to the proposed so-called " satellite " towns from the factories which will inevitably be built on the outskirts.

Some years ago a large glass works made arrangements to use town gas instead of raw producer gas. The results were very encouraging in many directions. The writer is therefore tempted to suggest that the staff of a factory should be free to concentrate on the production of the goods which it is intended to make and should not have to consider problems of gas making. Gas ought to be supplied at a reasonable price from large producing units such as gas undertakings. Substantial savings would accrue. Such a scheme would naturally be particularly effective for the smaller works existing in the non-ferrous industry.

SECTION D.
HIGH TEMPERATURE PROCESSES—*continued*

SESSION II. Furnace Design

Chairman of Session: MR. H. SOUTHERN
CHAIRMAN OF THE SOCIETY OF FURNACE BUILDERS

1. The Fundamentals of Industrial Furnace Design and Operation

By HERBERT SOUTHERN, A.M.I.MECH.E., M.AM.SOC.M.E., F.INST.F.

The design of industrial furnaces for such processes as melting, reheating and thermal treatment entails a most careful appraisal of the combined effect, upon life and operation, of many interdependent factors and this requires a knowledge of fuels and their combustion ; of heat transfer, thermodynamics and aerodynamics ; of diverse manufacturing processes ; of the chemical and physical reactions that occur during these processes ; of refractory materials and, indeed, of most subjects in industrial science.

It is nevertheless essential to stress that a carefully designed furnace cannot function efficiently unless properly controlled, satisfactorily maintained and continuously operated at or near its rating. Until the truth of this statement is fully realised a deplorable wastage of fuel will continue.

OPTIMUM EFFICIENCY AND THERMAL EFFICIENCY

Briefly, an efficient furnace is one which consistently maintains the desired output and quality of product on a minimum expenditure in fuel, auxiliary power, labour and maintenance. It is a furnace which operates at optimum efficiency.

A thermally efficient furnace is one in which the ratio of the heat absorbed by the charge to that in the fuel consumed is a maximum within the limiting conditions.

Optimum efficiency is the need of industry ; thermal efficiency is the immediate demand of the nation.

The first cannot be achieved without carefully operated furnaces of suitable design and construction.

The second, except in certain instances dependent upon manufacturing conditions and requirements, is generally found where optimum efficiency exists.

FUELS AND THE ATTAINMENT OF HIGH TEMPERATURES

In the selection of a fuel for a particular furnace, it is essential to consider its chemical composition, calorific value, physical characteristics, price and availability in relation to the duty to be performed. The fuel must be suitable for the economical production of the desired operating conditions and for the easy attainment and maintenance of the required working temperature.

In the case of high-temperature processes the theoretical or calorimetric temperature of combustion of a fuel is no criterion of its suitability. Consideration must be given to the combined effect upon the ultimate temperature, of the fuel/air ratio likely to be employed, of the conditions of mixing, of the emission of heat during combustion and of dissociation. This is a complex problem, but a solution is possible by a logical approach based upon observations in practice.

In furnaces of known characteristics employed on different processes and consuming different fuels, the maximum temperatures actually attained can be pyrometrically measured. From the observed temperature in any furnace the heat content of the products of combustion per unit of fuel can be computed and by comparison with the net thermal input per unit of fuel to the working chamber a ratio is obtained which may be called the " pyrometric efficiency " of the furnace. This figure ranges from 0·7 to 0·8 in continuous furnaces for steel mills and from about 0·7 to 0·75 in open-hearth steel melting furnaces. The temperatures in the continuous furnaces range from 1300° C. to 1500° C. (2372° F. to 2732° F.) and those in the open-hearth steel melting furnaces may even approach 1950° C. (3542° F.). A knowledge of the " pyrometric efficiencies " attained in practice is obviously of great value in the design of new furnaces. It provides a means of computing the required net heat input per unit of fuel to any furnace chamber, to ensure the attainment of the desired maximum temperature.

For instance, consider the proposed use of blast-furnace gas in a continuous billet-heating furnace to operate at 1400° C. (2552° F.) at the forehearth. Assume that the fuel has a gross calorific value of 93·5 B.Th.U. per cubic foot and a net value of 91·8 B.Th.U. per cubic foot. If the " pyrometric efficiency " of the furnace is 0·78, to what temperatures must the gas and air supplies be preheated to achieve the desired working conditions ?

The required temperature at the forehearth is 1400° C. (2552° F.) and if the products of combustion contain 10 per cent. excess air it is first necessary to determine their heat content. Fig. 20 shows the sensible heat content of the products of combustion of blast furnace gas and it will be observed that the products of perfect combustion at 2552° F. contain 90 B.Th.U. The heat in 10 per cent. excess air is 3·3 B.Th.U., therefore the total heat content of the products per cubic foot of gas is 93·3 B.Th.U. The net thermal input to the furnace chamber per cubic foot of gas, with a " pyrometric efficiency " of 0·78 must therefore be :—

$$\frac{93{\cdot}3}{0{\cdot}78} = 119{\cdot}6 \text{ B.Th.U.}$$

As the net calorific value of the gas is 91·8 B.Th.U. it is evident that 27·8 B.Th.U. must be provided by the preheating of the gas and air supplies. Fig. 20 again indicates that the gas supply would have to be preheated to 750° F. (399° C.) to introduce 13 B.Th.U., and the theoretical air supply be preheated to 1300° F. (705° C.) to introduce 15 B.Th.U. Other temperatures of preheat could be selected to give an identical result, but those chosen are typical of practice.

An existing continuous furnace fired with blast-furnace gas is heating 25 tons of blooms per hour to rolling temperature, with the gas preheated to 400° C. (752° F.) and the air preheated to 700° C. (1292° F.).

The maximum temperature attainable in a furnace can be mathematically expressed in relation to the controlling factors, but the equation cannot be directly employed in the design of a new furnace without foreknowledge of the hourly fuel consumption, the ratio of the heat losses in the chamber to the heat absorbed by the charge, and the temperature of the waste gases at the outlet ports. The interdependence of influencing factors is one of the difficulties of furnace design and for this reason a step by step procedure of development is necessary in all cases.

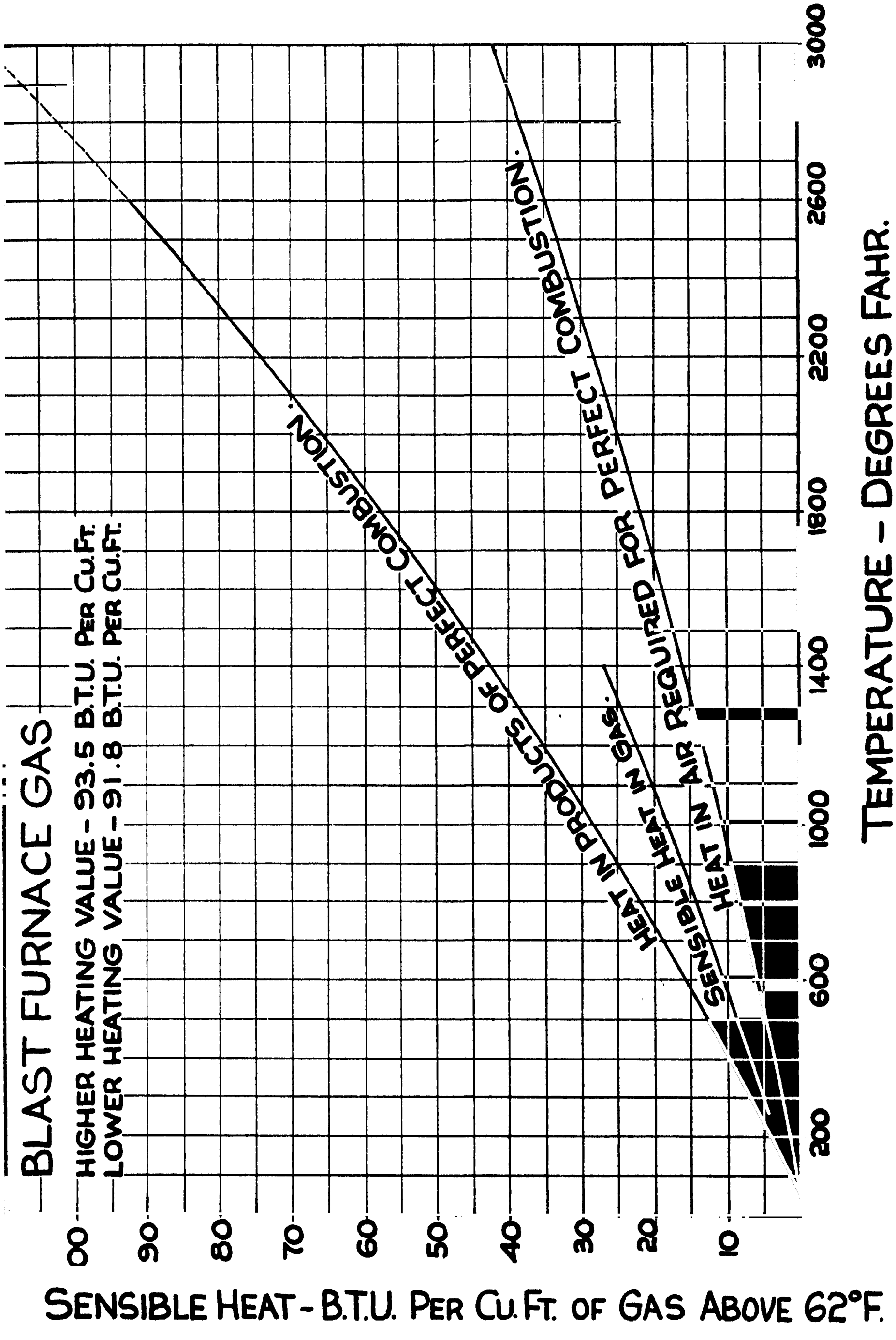

FIG. 20

HEAT LIBERATION

The heat energy within a fuel is released by combustion, but the conditions of burning control both the rate and degree of liberation and have a pronounced effect upon the characteristics of the resultant flame. Because of this fact a wide range of dissimilar heating conditions can be produced from one class of fuel. The combustion of different fuels by diverse methods of firing therefore provides an almost unlimited range of flames and atmospheres for industrial use.

The combustion of city gas in a tunnel burner of recent design produces, for instance, a very different heating condition from that evolved by the combustion of coal on the grate of a simple hand-fired reheating furnace. In the burner, the gas and air supplies are premixed in controlled proportions before entry to a special combustion tunnel and heat energy is almost instantaneously released at an exceedingly high rate with a maximum intensity of temperature. On the grate combustion is slow and retarded, heat energy is gradually released and a long, lazy rolling flame is produced.

The different flames and atmospheres producible in practice have their respective spheres of application and in the development of a furnace for a particular process it is imperative to select the right type of combustion equipment for the fuel to be consumed and the duty to be performed.

Solid fuels are consumed on grates or mechanical stokers, but pulverised and liquid fuels require burners. Port systems are needed for some of the industrial gases and burners are essential for the others. From an earlier remark it is obvious that the design of grates, stokers, burners and port systems for the combustion of different fuels of widely varying characteristics is a problem that is largely controlled by the diverse needs and requirements of industry. Although perfect combustion without excess air is the constant aim of fuel technologists it has to be remembered that the requirements of industry are not always met by this condition.

In the tunnel burner just described, the combustion efficiency is high but in the grate it is relatively low, yet both conditions are essential and indeed ideal for certain thermal processes. If the applications were reversed it would be impossible to achieve the results desired and this important fact cannot be ignored.

The selection of the most suitable combustion equipment for a particular fuel and process is a matter of experience. The correct application of the equipment in relation to the desired conditions of temperature and heat distribution is nevertheless a complex problem.

HEAT TRANSMISSION

In every industrial furnace heated by the combustion of fuel, the transfer of thermal energy to the charge is effected by radiation and convection from the hot gases. Exothermic and endothermic reactions also occur in certain processes and the heat liberated or absorbed has to be duly considered.

The actual mechanism of heat transfer is involved and the attainable rate of transmission in any furnace depends upon the relative areas, temperatures and emissivities of the refractory walls and charge, and upon the dimensions, shape, temperature, analysis, luminosity, emissivity and velocity of the mass of gas within the heating chamber.

Now in the development of a new furnace many of the factors which influence and control thermal transfer cannot be evaluated until the dimensions and shape of the heating chamber are known. The customary procedure is an approximation of the size and general proportions of the chamber, on the basis of accumulated knowledge and experience. This involves most careful consideration of the desired quality and output of product in relation to the effective liberation and utilisation of the heat energy in the fuel to be consumed. It is then essential to check the thermal characteristics of the selected chamber by application of the basic laws of heat transfer and, if necessary, to modify the dimensions until a state of balance is achieved between heat transmission, heat absorption and fuel consumption at the required hourly rate of production. From this step by step process, a heating chamber is developed that is neither too large nor too small for the duty to be performed.

In practice, the maximum permissible combined rate of thermal transfer, by radiation and convection, depends upon numerous factors. It is controlled in certain heat treatment processes by the temperature difference that can be permitted within the mass of material receiving heat. In open-hearth steel melting furnaces it is only limited by the stability of the refractory linings in relation to the general conditions of operation.

A detailed consideration of the theory of industrial heat transfer is impossible within the scope of this paper, but the simple mathematical relationship between heat transmission and heat absorption is expressed below :—

$$\alpha\,(\theta_F-\theta_C)\,dt = \frac{W}{A}\,.\,c\,.\,d\theta_C \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (1)$$

It is therefore evident that :—

$$t = \frac{Wc}{\alpha A}\,.\,log_e \left(\frac{\theta_F-\theta_{CA}}{\theta_F-\theta_{CE}}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (2)$$

This equation expresses the heating time in relation to other factors, but its useful application depends upon a knowledge of the diverse rates of thermal transfer attainable in practice under different operating conditions.

The nomenclature is as follows :—

t = heating time . . . . hours.
A = actual heat receiving surface of the charge . . . . . sq. ft.
c = mean specific heat of the material receiving heat . . . B.Th.U./Lb./° F.
W = total weight of the charge . . lb.
α = average rate of heat transmission . B.Th.U./Sq. Ft./Hr./° F.
θ_F = temperature of the furnace . . ° F.
θ_{CA} = initial temperature of the charge . ° F.
θ_{CE} = final temperature of the charge . ° F.

The application of Equation (2) will be illustrated by an example. A simple furnace normally operating at 950° C. (1742° F.) is employed for the heating of plates from 15° C. (59° F.) to 900° C. (1652° F.). The hearth is

7 ft. wide by 5 ft. deep, and a single plate 1-in. in thickness measuring 6 ft. by 4 ft. is to be heated. What will be the heating time when α has a mean value of 25 B.Th.U./Sq. Ft./Hr./° F. ?

Now $A = 24$ sq. ft.

$c = 0\cdot16$

$W = 980$ lb.

$\theta_F = 1742^\circ$ F.

$\theta_{CA} = 59^\circ$ F.

$\theta_{CE} = 1652^\circ$ F.

therefore

$$t = \frac{980 \times \cdot16}{25 \times 24} \times \log_e \left(\frac{1742^\circ - 59^\circ}{1742^\circ - 1652^\circ}\right)$$

$$= 0\cdot2613 \times 2\cdot925$$

$$= 0\cdot764 \text{ hours or } 46 \text{ minutes.}$$

With a greater or smaller rate of heat transfer than 25 B.Th.U./sq. ft./Hr./° F. the heating time would be proportionately decreased or increased, therefore equation (2) will only give results in accord with practice when the correct coefficient of heat transfer for the particular operating conditions is employed. It is evident that the selection or determination of the correct value of α is a matter of experience.

Equation (2) as presented, is unsuitable for general use in relation to all heating processes. For instance, in the calculation of the time to heat ingots, blooms, rounds, slabs and special shapes of medium or large size, as distinct from thin sheets, plates, flats and small billets, the temperature conditions within the charge have to be considered. It is then essential to use a modified form of equation (2).

All problems in industrial heat transfer should in fact be approached from first principles with due consideration, in each instance, of every influencing factor.

HEAT UTILISATION WITHIN A FURNACE CHAMBER

The thermal energy liberated in the working chamber of a furnace is only partially transmitted to the charge. Some of the remaining heat is dissipated by the structure and the rest is conveyed to the exhaust circuit by the products of combustion. The heat dissipated by the furnace structure is a total loss, but part of the heat conveyed by the waste gases to the exhaust circuit can be recovered and returned to the heating chamber by recuperation or regeneration.

The temperature and pressure conditions within the chamber ; the size, construction and general state of repair of the chamber itself ; the use of water-cooled or other heat-absorbing devices ; the size, fit and frequency of operation of the doors ; and the degree to which thermal equilibrium is attained in the brickwork, are the main controlling factors in relation to the heat loss from the structure.

The temperature of the products of combustion at the outlet ports ; the amount of air employed for combustion ; the quantity of air subsequently infiltered and the degree to which combustion is complete, control the amount of heat conveyed to the exhaust circuit by the waste gases.

The heat input to a furnace chamber can be expressed by the equation :—

$$H_I = H_U + H_W + H_G \tag{3}$$

therefore the heat available for use in the chamber is :—

$$H_A = H_I - H_G = H_U + H_W \tag{4}$$

The ratio of the heat absorbed by the charge to that available, is therefore :—

$$\phi = \frac{H_U}{H_A} = \frac{H_U}{H_I - H_G} = \frac{H_U}{H_U + H_W} \tag{5}$$

The ratio of the heat absorbed and dissipated by the structure of the furnace chamber to that available for use within it, is consequently :—

$$1 - \phi = \frac{H_W}{H_A} = \frac{H_W}{H_I - H_G} = \frac{H_W}{H_U + H_W} \tag{6}$$

In these and all subsequent equations the following nomenclature is employed :—

H_I = Net heat input to furnace chamber . B.Th.U./hr.
H_A = Heat available for use within chamber . B.Th.U./hr.
H_U = Heat absorbed by charge . . . B.Th.U./hr.
H_W = Heat losses from chamber . . . B.Th.U./hr.
H_G = Heat content of outgoing products of combustion . . . . . . B.Th.U./hr.
ϕ = A factor = $\frac{H_U}{H_A}$
θ_F = Maximum temperature desired in chamber . . . . . . ° F.
θ_E = Temperature of outgoing products of combustion . . . . . . ° F.
θ_{CA} = Initial temperature of charge . . ° F.
θ_{CE} = Final temperature of charge . . ° F.
h_f = Net calorific value of fuel . . . B.Th.U./unit.
h_r = Heat returned to furnace chamber by recuperation or regeneration . . B.Th.U./unit of fuel.
W = Output = weight of material heated . lb./hr.
c = Mean specific heat of charge . . B.Th.U./lb./° F.
w_{ga} = Weight of products of combustion per unit of fuel at θ_F . . . . . lb.
c_{ga} = Mean specific heat of products of combustion up to θ_F . . . . . B.Th.U./lb./° F.
w_{ge} = Weight of products of combustion per unit of fuel at θ_E . . . . . lb.
c_{ge} = Mean specific heat of products of combustion up to θ_E . . . . . B.Th.U./lb./° F.
Ψ = Pyrometric efficiency.
Q = Fuel consumption . . . . . units/hour.
η = Overall thermal efficiency of furnace.
$a = (h_f + h_r) = \left(\frac{w_{ga}.c_{ga}.\theta_F}{\Psi}\right)$ . . B.Th.U./unit of fuel.
$b = (w_{ge}.c_{ge}.\theta_E)$ . . . . . . B.Th.U./unit of fuel.

The heat absorbed by the charge per hour is :—

$$H_U = (\theta_{CE} - \theta_{CA}).W.c \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

Now according to Equation (4) :—

$$H_A = H_I - H_G$$

therefore :—

$$H_A = Q[(h_f + h_r) - (w_{ge}.c_{ge}.\theta_E)] = Q(a\text{-}b) \quad . \quad . \quad . \quad . \quad (8)$$

This equation presupposes the complete liberation of the heat in the fuel. By combining Equations (5), (7) and (8) it is evident that :—

$$\phi = \frac{H_U}{H_A} = \frac{(\theta_{CE} - \theta_{CA})W.c.}{Q[(h_f + h_r) - (w_{ge}.c_{ge}.\theta_E)]} = \frac{H_U}{Q(a\text{-}b)} \quad . \quad . \quad . \quad (9)$$

The true " pyrometric efficiency " of a furnace is :—

$$\Psi = \frac{w_{ga}.c_{ga}.\theta_F}{(h_f + h_r)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

therefore :—

$$(h_f + h_r) = \frac{w_{ga}.c_{ga}.\theta_F}{\Psi} = a \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

By combining Equations (9) and (11) :—

$$\phi = \frac{(\theta_{CE} - \theta_{CA}).W.c}{Q[(\frac{w_{ga}.c_{ga}.\theta_F}{\Psi}) - (w_{ge}.c_{ge}.\theta_E)]} = \frac{H_U}{Q(a\text{-}b)} \quad . \quad . \quad . \quad . \quad (12)$$

The hourly consumption of fuel is :—

$$Q = \frac{H_W + (\theta_{CE} - \theta_{CA})W.c.}{(\frac{w_{ga}.c_{ga}.\theta_F}{\Psi}) - (w_{ge}.c_{ge}.\theta_E)} = \frac{H_W + H_U}{(a - b)} \quad . \quad . \quad . \quad . \quad (13)$$

Let us now consider the overall efficiency of a furnace. As stated earlier in the paper it is the ratio of the heat actually absorbed by the charge to that in the fuel consumed. On the basis of the net calorific value of the fuel it is evident that :—

$$\eta = \frac{(\theta_{CE} - \theta_{CA}).W.c}{Q.h_f} = \frac{H_U}{Q.h_f} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

When Equations (12) and (14) are combined, then :—

$$\phi = \frac{\eta.h_f}{(\frac{w_{ga}.c_{ga}.\theta_F}{\Psi}) - (w_{ge}.c_{ge}.\theta_E)} = \frac{\eta.h_f}{(a - b)} \quad . \quad . \quad . \quad . \quad (15)$$

In practice ϕ is less than unity owing to the thermal losses from the structure of the heating chamber, but Equation (15) clearly indicates that it must approach this figure if a high degree of thermal efficiency is desired. This is an important fact which cannot be ignored in the design of furnaces.

The use of the foregoing equations will be illustrated in relation to the development of a blast-furnace gas fired, continuous recuperative furnace for the heating of steel billets. The following conditions are assumed :—

n_f = 91·8 B.Th.U./cu. ft.
Ψ = 0·78
θ_F = 1400° C. = 2552° F.
θ_E = 1050° C. = 1922° F.
θ_{CE} = 1300° C. = 2372° F.
θ_{CA} = 15° C. = 59° F.
W = 9,000 lb.
c = 0·16 B.Th.U./lb. ° F.

Let it also be assumed that the products of combustion contain 6 per cent. excess air at the forehearth and 20 per cent. at the outlet ports.

Reference to Fig. 20 shows that :—

$$w_{ga}.c_{ga}.\theta_F = 91\cdot 9 \text{ B.Th.U.}$$

and

$$w_{ge}.c_{ge}.\theta_E = 67\cdot 4 \text{ B.Th.U.}$$

According to Equation (15) :—

$$\phi = \frac{91\cdot 8\,\eta}{\frac{91\cdot 9}{0\cdot 78} - 67\cdot 4}$$

therefore :

$$\phi = \frac{91\cdot 8\,\eta}{117\cdot 9 - 67\cdot 4} = 1\cdot 818\,\eta$$

For the limiting condition $\phi = 1$, the ideal efficiency would be 0·55 or 55 per cent., but this could only be achieved in a working chamber which neither absorbed nor dissipated thermal energy. The losses which actually occur in practice must therefore be taken into consideration. These vary considerably, even in furnaces of similar type and are influenced by the thickness of the walls and arches ; by the thermal characteristics of the refractories employed and by the extent to which insulating materials are used.

In highly efficient continuous furnaces ϕ rarely exceeds 0·85, and this figure can only be achieved under full-load operating conditions after the attainment of thermal equilibrium. If, however, we assume this value in the example under consideration, then :—

$$\phi = 0\cdot 85 = 1\cdot 818\,\eta$$

therefore :—

$$\eta = 0\cdot 4676$$

In other words, the highest thermal efficiency attainable would be approximately 47 per cent.

The minimum hourly consumption of blast-furnace gas, according to Equation (14) would be :—

$$Q = \frac{1}{0\cdot 4676} \times \frac{(2372-59)\times 9000 \times 0\cdot 16}{91\cdot 8}$$
$$= 77{,}610 \text{ cubic feet.}$$

According to Equation (8) the heat available for use in the heating chamber would be :—

$$H_A = 77610\,(117\cdot 9 - 67\cdot 4)$$
$$= 3{,}919{,}300 \text{ B.Th.U.}$$

The heat dissipated by the structure of the chamber, according to Equation (6), would therefore be :—

$$H_W = (1-\phi)\times 3{,}919{,}300$$
$$= (1-0\cdot 85)\times 3{,}919{,}300$$
$$= 587{,}900 \text{ B.Th.U.}$$

This figure represents the total permissible heat loss per hour, after the attainment of thermal equilibrium. In a furnace of the size under consideration the heating chamber would have to be most effectively insulated. It is essential to observe that Equations (4) to (15) only relate to thermal balance within a heating chamber when all the influencing factors are in equilibrium.

Now in continuous furnaces, and particularly in those which are solely fired from the end, the temperature θ_E noticeably fluctuates in relation to the hourly rate of production and in practice it is found that an optimum condition of equilibrium between output and thermal efficiency is attained under certain conditions of operation. This is an important fact which designers have to consider in the development of new furnaces. In their aim to achieve the highest degree of thermal efficiency they endeavour to secure an optimum condition of equilibrium at full rating.

Fig. 21 refers to the furnace considered in the example and shows the theoretical relationship between gas consumption and output for different temperatures, θ_E, ranging from 1500° to 2550° F. The ratio $\frac{Q}{W}$ between gas consumption and output is also indicated in relation to the thermal efficiency η.

In practice θ_E would range from 1750° F. at low rates of production to 2000° F. at full rating and, within these limits, the ratio Q/W would follow the dot-dash line in Fig. 21. For these conditions the relationship between fuel consumption, output and efficiency is indicated below :—

W Lb. of steel per hour	$\frac{Q}{W}$ Cu. ft. of gas per lb. of steel	Q Cu. ft. of gas per hour	η Thermal efficiency
1000	16	16000	0·252
3000	10	30000	0·403
5000	9·1	45500	0·443
7000	8·75	61250	0·46
9000	8·7	78300	0·463

The influence of the hourly rate of production upon the gas consumption per lb. of steel is clearly indicated and shows that continuous operation, at or near the rated capacity of the furnace, would be essential to fuel economy.

Fig. 22 relates to the same furnace and graphically illustrates the interdependence of $\frac{Q}{W}$, η, ϕ and θ_E. To achieve a high degree of thermal efficiency, ϕ must approach unity and θ_E must be as low as possible.

It is essential to stress that the results indicated by Figs. 21 and 22 would be unattainable without efficient recuperation. The gas would have to be preheated to at least 700° F. and the air to not less than 1250° F.

THE UTILISATION OF WASTE HEAT

To achieve a high thermal efficiency the heat input to a furnace must be utilised to a maximum possible degree. Some form of recuperation or regeneration is therefore essential in most furnaces to reclaim heat from the outgoing products of combustion. This heat is generally utilised to preheat the air required for combustion, but in certain instances it is employed for the preheating of both the fuel and the air.

The use of recuperators or regenerators has a pronounced effect upon the consumption of fuel, but that is not their sole purpose. In certain furnaces it is impossible to achieve the desired working conditions without adequate preheating of the air, or the fuel and air, and this fact must never be overlooked. An open-hearth steel-melting furnace is a case in point. A furnace fired with blast-furnace gas and used for the reheating of steel to rolling temperature would similarly fail to function without heat recuperation or regeneration to the required degree.

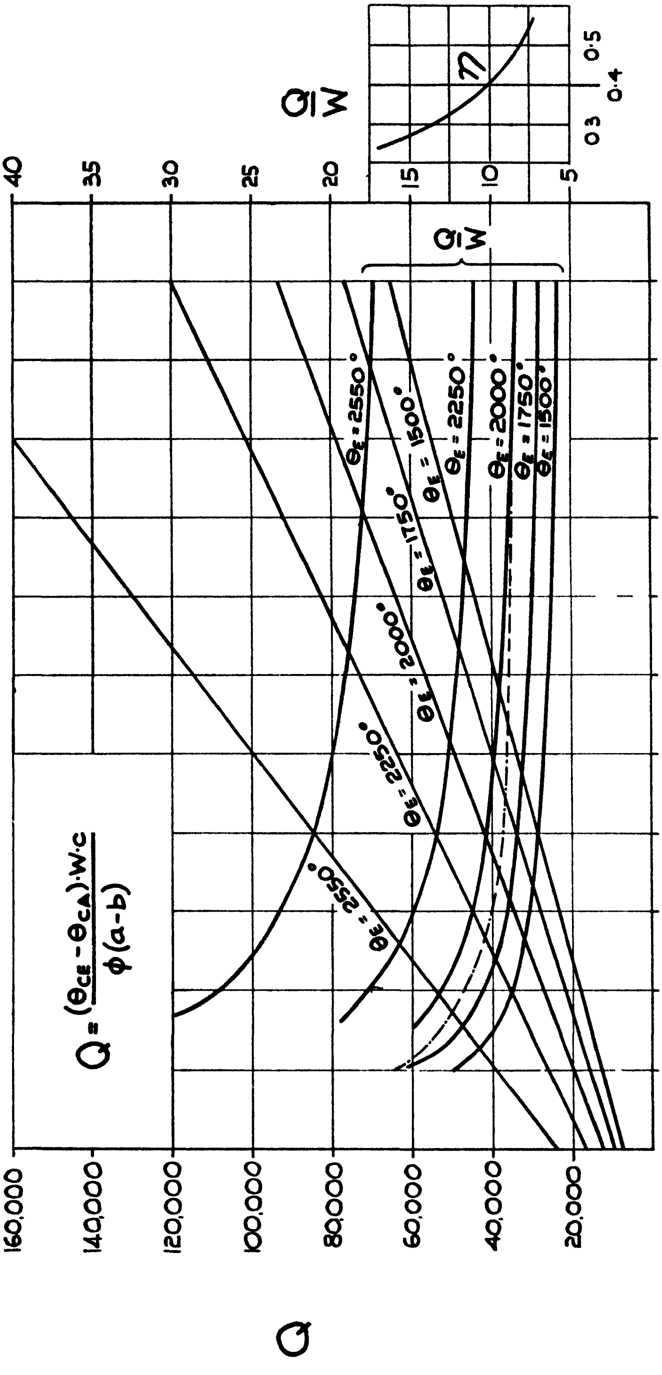
Q = (θ_CE − θ_CA)·W·c / φ(a−b)
Q
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
W
2000
4000
6000
8000
10000
Q/W
40
35
30
25
20
15
10
5
0·3
0·4
0·5
η
θ_E = 2550°
θ_E = 2250°
θ_E = 2000°
θ_E = 1750°
θ_E = 1500°

FIG. 21.

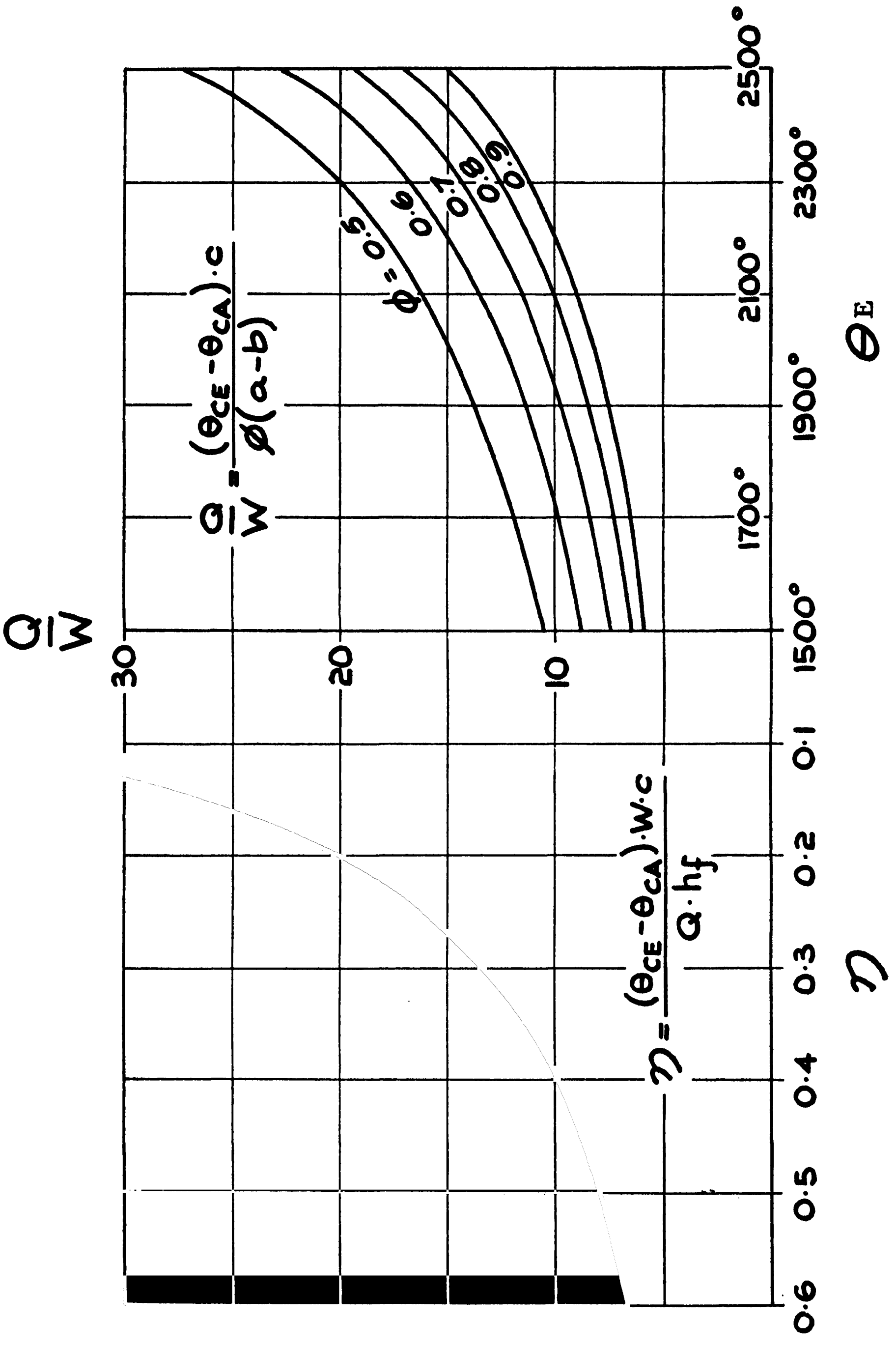
Q/W
30
20
10
Q/W = (θ_CE - θ_CA)·c / φ(a-b)
φ = 0·5
0·6
0·7
0·8
0·9
1500°
1700°
1900°
2100°
2300°
2500°
θ_E
0·1
0·2
0·3
0·4
0·5
0·6
η = (θ_CE - θ_CA)·W·c / Q·h_f
η

FIG. 22.

The quantity of heat recoverable depends upon the temperature and composition of the products of combustion at the inlets and outlets of the recuperators or regenerators and upon the thermal losses from the encasing structures. In the case of furnaces operated by natural draught the degree of heat reclamation is limited by the temperatures required at the chimneys to maintain circulation. A greater degree of recovery is possible in furnaces with mechanical draught, but it is then essential to take special precautions to avoid short-circuiting in the recuperators, or air infiltration in the regenerators.

The design of efficient recuperators and regenerators demands wide knowledge and experience, but when they are correctly proportioned, applied and used they greatly conserve thermal energy.

It has been shown in Equation (13) that the consumption of fuel in a recuperative or regenerative furnace is :—

$$Q = \frac{H_W + H_U}{h_f + h_r - b} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (13)$$

The consumption of fuel in a furnace without a recuperator or regenerator is therefore :—

$$Q = \frac{H_W + H_U}{h_f - b} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (16)$$

Recuperation or regeneration effects the following fuel saving per cent. :—

$$100 \times \left(\frac{hr}{h_f + h_r - b}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (17)$$

This equation is graphically presented in Fig. 23, and applies to any fuel. It indicates the economy theoretically attainable under identical operating conditions.

Whilst recuperators and regenerators are essential to fuel economy, extreme care must be exercised in their use for the preheating of gaseous fuels owing to the dissociation which occurs under certain conditions.

If all the furnaces now in operation without any system of heat recovery could be replaced by carefully designed and correctly operated recuperative or regenerative furnaces, then a fuel saving ranging from about 8 per cent. in certain instances up to 33 per cent. or more in other cases would be achievable. These figures are based upon the recovery of about 20 per cent. of the waste heat in low-temperature furnaces up to 50 per cent. in furnaces operating at temperatures around 2000° F.

THE PRESENT AND THE FUTURE

This paper outlines the basic principles of design and operation, but does little more than indicate the general method of approach to the development of furnaces.

The practical application of the basic laws of heat transfer ; the design of combustion chambers ; the development of efficient melting and reheating chambers ; the calculation of port, flue and chimney dimensions ; the computation of recuperators and regenerators ; the determination of thermal storage and heat losses ; the effect upon efficiency of intermittency of operation ; and the selection and application of refractory and insulating materials are but

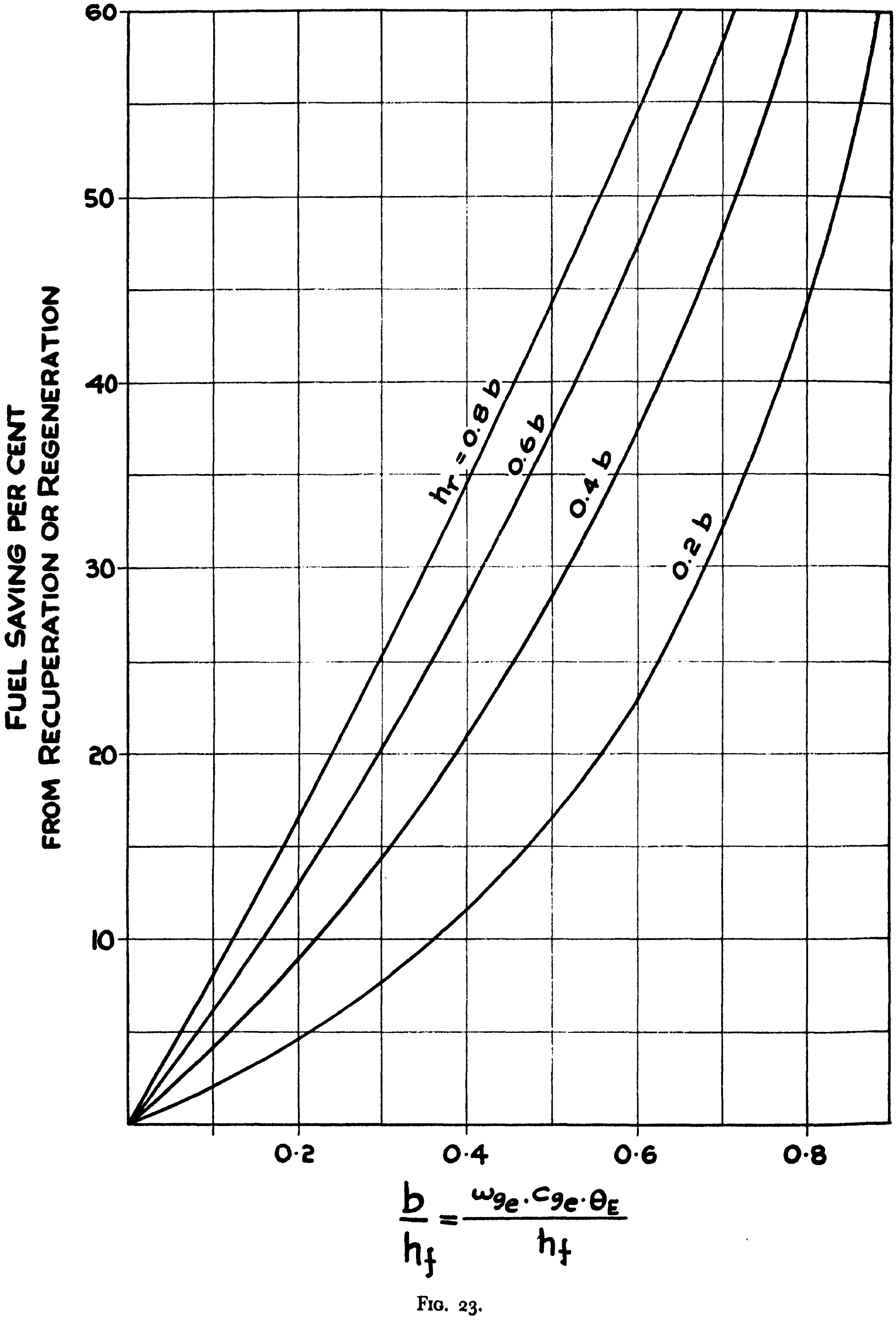
FUEL SAVING PER CENT
FROM RECUPERATION OR REGENERATION
60
50
40
30
20
10
0·2
0·4
0·6
0·8
$h_r = 0.8\,b$
0.6 b
0.4 b
0.2 b
$\dfrac{b}{h_f} = \dfrac{w_{g_e} \cdot c_{g_e} \cdot \theta_E}{h_f}$

FIG. 23.

a few of the many aspects of design which have neither been mentioned nor explained, yet all are of vital import in relation to the installation of successful furnaces.

The subject of industrial furnace design is too exhaustive for presentation within the limits of a single paper, therefore the primary purpose of this contribution is to indicate and stress the main factors which affect both fuel consumption and thermal efficiency.

To achieve a low consumption of fuel per ton of product the following conditions are essential :—

(*a*) *The total hourly heat loss from the furnace structure must be a minimum.*—The walls should be effectively insulated or otherwise entirely built of refractory materials of low thermal conductivity, low specific heat and low density. As the thermal loss is a minimum after the attainment of thermal equilibrium, intermittency of operation or frequent lighting-up and shutting-down should be avoided. The doors of the furnace must be limited in number and size. They should fit tightly to avoid " flaming-out " or air infiltration. The height of lift must be set at the minimum practical requirement. Unnecessary operation of the doors should be avoided. Water-cooled devices must be limited to the minimum practical requirement.

(*b*) *The hourly output of heated material from the furnace must be a maximum.*—All furnaces should be loaded to capacity and continuously operated in this manner.

(*c*) *The conditions of combustion must be as near the ideal as possible.*—The liberation of heat per unit of fuel must be a maximum and this demands careful control and mixing of the fuel and air supplies. If an excess of air is required at the combustion zone it should be effectively controlled and limited.

(*d*) *The temperature of the gases at the outlet ports of the heating chamber must be a minimum.*—This temperature depends upon the type of furnace and its purpose. Continuous furnaces are more efficient than batch-type furnaces because of the lower exit temperature of the gases.

(*e*) *Excess air in the products of combustion at the outlet ports of the heating chamber must be minimised.*—The furnace structure must be sound. Air infiltration must be combatted. The furnace pressure at hearth level should slightly exceed that of the external atmosphere at the same point. Frequent and unnecessary operation of the doors must be avoided.

(*f*) *The heat in the outgoing products of combustion must be recovered to the maximum possible extent and returned to the heating chamber.*—Recuperators or regenerators should be employed wherever possible, but continuity of furnace operation is essential to their success.

The overall thermal efficiency of existing furnaces fired with solid, pulverised, liquid and gaseous fuels ranges in general from about 4 per cent. to 55 per cent. Most furnaces are, however, within the range of 10 per cent. to 35 per cent. and the low thermal efficiency of many is due to improper usage and control.

But what of the future ?

The heat absorbed and dissipated by the brickwork of furnaces is irrecoverable and represents a tremendous annual wastage of fuel. There is, therefore, an imperative need for refractory materials of suitable characteristics to reduce these losses. Hot-face insulating bricks are a development in the right direction, but they can only be employed in certain instances. Materials of minimum density, low thermal conductivity and low specific heat are required for all conditions of application and if they were available the average thermal efficiency of furnaces could be immediately and appreciably increased. The adverse effect of intermittent furnace operation upon fuel consumption could also be effectively combatted.

The use of natural draught for industrial furnaces is responsible for a greater wastage of fuel than is generally realised. The loss in each case is a function of the chimney height and of the total resistance to gas flow within the furnace. Satisfactory furnace performance depends upon adequate draught and the creation of natural draught depends upon the constant availability of heat. For instance, the production of a total theoretical draught of 0·5 in. w.g. in a chimney 60 ft. high requires a mean temperature of 675° F. within the stack. If the products of combustion contain 50 per cent. excess air owing to infiltration, and the fuel consumed in the furnace is coal with a net calorific value of about 12,400 B.Th.U. per lb., then more than 18 per cent. of the heat input is employed for the creation of draught. Thus, in a furnace consuming 5 cwt. of coal per hour and operating 120 hours per week for 45 weeks per year, about 250 tons of coal per annum are used to maintain circulation of the hot gases in the working chamber and flues. If this fuel were available for re-use in a billet-heating furnace with an overall efficiency of 30 per cent. it would raise about 2,500 tons of steel to a rolling temperature of 2300° F. With waning fuel supplies and increasing costs greater attention should be paid to the wider use of mechanical draught. Its adoption is impracticable in certain instances, but its employment in other cases would lead to a considerable saving of fuel.

Consideration should also be given to the use or partial use of oxygen for the combustion of fuels. Some of the higher temperatures required in practice would be more easily attained and a greater use could be made of lean fuels of low calorific value. An investigation of its use and effect upon thermal transfer, heating chamber design, fuel consumption and operating costs is worth while.

These are but pointers to progress in the achievement of greater economy in the consumption of industrial fuels.

The attainment of the desired goal depends upon effective collaboration between designers, fuel technologists, furnace operators, and those engaged in the supply and manufacture of refractory materials.

Are all the users of industrial furnaces prepared to foster this collaboration ?

2. Refractories

By DR. W. J. REES

Dr. Rees, as chairman of the Refractories Section of The British Ceramic Society, introduced the papers dealing with refractories. He pointed out that the overall efficiency of a furnace depended on other things besides fuel consumption and only when adequate data was obtained on fuel consumption, furnace repairs, maintenance, loss of output during repairs, etc., could a true picture be obtained. Overall efficiency could sometimes be increased by water-cooling or air-cooling the refractories so as to increase their life rather than by insulation. He supported Mr. Southern's plea for greater collaboration between furnace designers and users and the manufacturers of refractories, this being particularly valuable in ensuring that the right refractory was chosen to meet the conditions. There must be complete knowledge of the conditions as to temperature, atmosphere, dust, fume, etc.

The need was emphasised for efficient furnace building, and for the use of well-made bricks requiring the minimum of jointing. The type of jointing material used was very important. Manufacturers of refractories were fully aware of the need to provide bricks that would be efficient under the increasingly severe service conditions resulting from higher working temperatures and greater outputs. A factor of major importance was the cost of the refractory in relation to the overall efficiency of the furnace.

3. The Selection and Use of Hot-Face Insulating Bricks

By L. R. BARRETT, B.A., B.SC., M.S., A.R.I.C.

The author pointed out that much of the fuel used in this country was consumed in installations working at a moderate temperature. Heat losses from a high-temperature furnace may occur from parts of the structure that operate at lower temperatures. Table I, based on calculations by J. M. Ferguson,[1] was quoted in illustration. These referred to two open-hearth steel-melting furnaces. Of the heat losses, 43·5 per cent. and 37·1 per cent. respectively were from walls with a hot-face temperature below 1400° C.; the lower figures in the newer (Venturi) furnace were due to insulation which would be applied most easily to the regenerators and gas mains.

TABLE I

TOTAL HEAT LOSSES FROM THE PARTS OF TWO OPEN-HEARTH FURNACES, ABOVE AND BELOW A HOT-FACE TEMPERATURE OF 1400° C.

	Therms per hour			
	1918 Furnace		Venturi Furnace	
	When new	Average over working life	When new	Average over working life
Parts with hot-face temperature above 1400° C.	83·0	108·5	73·5	84·7
Parts with hot-face temperature below 1400°C.	76·7	83·5	46·1	50·0

A ceramic tunnel kiln was the subject of methodical study by E. Rowden in 1936.[2] From his calculations it emerged that 58·5 per cent. of the heat lost by radiation and convection was dissipated from the cooling and preheating zones, where, of course, the hot-face temperatures were lower than in the firing zone. The two former zones accounted for 67 per cent. of the length. It was noted that the heat loss per unit area from the crown of the kiln was least in the firing zone, because thicker insulation had been used, including 4½ in. of hot-face insulating brick behind firebrick.

ECONOMIC THICKNESS CALCULATIONS

A useful purpose would be served by using such surveys as those of Ferguson or Rowdon to calculate the economic thickness of insulation at each point.

It would be found sometimes that the inner refractory lining would be exposed to undue stresses if built of firebrick. In these cases, it can often be shown that the entire cost of replacing firebrick by super-refractories would be covered in a comparatively short time by the value of the fuel saved. A case in point was a continuous steel-billet reheating furnace where, by using sillimanite bricks in place of good-class fireclay over the soaking zone, adequate roof insulation could then be recommended.

RELIABILITY OF THERMAL DATA

The economic thicknesses so calculated are often rather surprising. Such calculations should surely be made before the final design of major installations is agreed. The data used should be of recent origin and reliable, as errors in the thermal conductivity are sometimes found.

The heat capacity of brickwork is not subject to much doubt as the weight per unit volume and the temperature rise are fairly easily measured, whilst the specific heat is not sensitive to changes of composition.

REFRACTORIES WITH CONTROLLED PROPERTIES

How the properties of the materials Nature has given us can be modified to suit endless and ever-stiffening demands has kept the refractories technologists busy. Structures have remained massive ; if the thermal resistance has been increased by thickening the walls, the heat absorbed by them has increased too. R. J. Sarjant[3] did much to educate us in that respect. When the walls of forge furnaces were made 4½ in. thick to reduce the time to heat up, the transmission losses during the latter part of the day became shockingly high. 600 B.Th.U. per sq. ft. per hour is a reasonable figure to aim at for the steady rate of transmission loss, corresponding to a surface temperature under still air conditions of 150° C.

TABLE II

HEAT STORAGE CAPACITY AND HEAT TRANSMISSION OF FIREBRICK WALLS

Thickness of firebrick wall in.	Hot-face temperature = 1300° C.	
	Heat storage capacity, B.Th.U./sq. ft.	Heat transmission at equilibrium, B.Th.U./sq. ft./hr.
22½	77,000	800
18	63,000	1,000
13½	48,000	1,300
9	33,000	1,900
4½	17,000	3,500

There is nothing to be gained by building very thin walls for furnaces on daily operation. Apart from the high heat transmission after about six hours of operating, half-brick thick walls tend to be leaky.

As is well known to furnace-builders, the thickness of walls and roof is dictated by considerations of mechanical stability, depending on the height of walls and the span of crowns and on the temperature. This has been altered a good deal in recent years by the introduction of hot-face insulating bricks and suspended walls and roofs. The lightness of the former often suggests the latter, though on account of the lower cost sprung arches are much commoner for medium and small spans.

The common refractory materials, fireclay and silica, when fabricated into building units run from about 90 to 120 lb. per cu. ft. in bulk density. The true density mostly falls within the range 150 to 170 in round figures. The porosities run from about 10 to 30 per cent. by volume, the higher figure applying to silica bricks. The manufacture of bricks from clay with porosities much in excess of these figures can be traced back for 50 years, but it was not until some 25 years ago that hot-face insulating bricks began to make their presence felt—at first in the U.S.A. and later in this country.

Most of the hot-face insulating bricks have densities in the region of 45 to 55 lb. per cu. ft. corresponding to a porosity of about 70 per cent. Bricks heavier than this usually have superior high-temperature durability to justify the increased weight. It is not possible to define the durability of a brick at operating temperatures from its bulk density. Failure in practice may start from one of several weaknesses. For instance, occasional over-rapid heating may crack certain bricks, which subsequently may loosen and allow portions of the structure to slip out of position. In another instance, excessive temperatures may cause shrinkage of an arch which sinks and removes the support from the bricks above which, being of rather low hot tensile strength, will tear. In yet another instance, a coating may have been applied too thickly, which, by its weight at temperatures of about 1400° C. when the clay brick is soft, may have pulled the surface away in positions above a fire-mouth. These properties—spalling resistance, shrinkage on reheating, hot tensile strength—are not related to weight per unit volume, but to such factors as firing temperature, grog content and texture. Nevertheless, when some sort of correlation can be seen, it is generally to indicate that the lighter the brick, the less durable it is. By and large, failures of the kind indicated are uncommon. The author has had the opportunity of observing, during the course of ten years, several large installations operating up to 1250° C. built throughout (except for the hearth) of hot-face insulating bricks, which have given complete satisfaction. Instances could be culled from (1) the steel industry, where these bricks are being used as standard practice in heat-treatment furnaces ; (2) the heavy clay industries, where quite a few round down-draught kiln crowns have been constructed of hot-face insulating bricks and given satisfaction to manufacturers of roofing tiles and blue bricks ; (3) the pottery industry, where many intermittent glost kilns have been re-lined with hot-face insulating bricks with reductions in fuel of from 10 to 25 per cent., with 15 per cent. as an average. The series of papers presented before the Institute of Fuel dealing with thermal insulation contained several reports of benefits accruing from hot-face insulation, but most of these were taken from American literature. British practice would appear to be more often conservative, using the hot-face bricks behind a fire-brick or silica-brick lining. Where the furnace is held at operating temperatures for a week or more this is also good thermal practice, but more effort should be made to use only light-weight bricks where the heating is intermittent or fluctuating.

MAXIMUM SAFE TEMPERATURE

It has been generally thought that if a hot-face insulating brick shrank appreciably at a certain temperature, so that this temperature was given as the highest practicable temperature of use, then it could be confidently recommended for long continued use under reasonably clean conditions up to a temperature about 200° C. lower.[4] For this reason 1200° C. has been given as the highest temperature to which hot-face insulating bricks can be subjected, if the life is to be equal to that of dense bricks. Under some circumstances, as, for instance, when clean producer gas or town gas is used for heating and the rate of heating and cooling is slow, it is stated that a good life is obtainable in the region of 1250° C.

A comparison of the laboratory test results in Table III with the author's knowledge of these bricks in service suggests that hot-face insulating bricks can be recommended for general use to within 100° C. of the temperature at which 1·0 per cent. shrinkage occurs in 2 hours in the laboratory test.

The measurements recorded in Table III have been made by the British Refractories Research Association, using for the most part the methods of test laid down in " Tentative Standard Methods for Testing Refractory Insulating Materials ", prepared by the Testing Committee of the British Refractories Research Association. The thermal conductivity is the mean of two sets of measurements made perpendicular to the 9 in. × 4½ in. and 9 in. × 3 in. faces respectively. In the " small prism " spalling test, the higher the figure the more resistant the brick is to spalling. An earlier set of figures referring to Brands B, C, D, E, F and G, and a discussion of the test methods was published in 1940.[5]

It has been urged[6] that where a battery of heating furnaces performing an identical operation is used, it would be more economical to adopt hot-face insulation even if the life of the lining were shorter than that of the customary dense firebricks. The cost of one extra furnace as a standby whilst re-lining was in progress would be more than justified by the fuel savings. This view has not been favoured by furnace suppliers, who have the psychology of the customer to contend with. The position is rather different where one or two furnaces only are used ; the process is interrupted and the cost may be high. Higher up the temperature scale, where dense refractories have a short life, the best modern practice is to re-line or patch at fixed intervals, coinciding with holiday periods.

Would it not be in the national interest to send teams of furnace, fuel and refractories technologists about the country, intensively studying selected furnace processes with an open mind ? During the recent war, considerable savings were effected by small improvements in furnace practice at the suggestion of trained engineers, often after quite a cursory look round. The post-war respite seems a good opportunity for a more searching analysis of furnace heat balances. From arm-chair estimates, the author would be inclined to say that several million tons of coal could be saved per annum by a uniform adoption of insulation practice, known from individual instances to be sound. Yet more could be saved by applying the recommendations of small teams of experts, after a thorough study had been made of the best insulation practice and possibilities in furnace processes.

HOT-FACE INSULATING BRICKS FOR USE ABOVE 1400° C.

Such studies would probably bring out a need for light-weight bricks made from super-refractories, such as sillimanite, silica, alumina and basic materials, both for hot-face duty and for backing-up behind 9 in. walls of dense refractories with hot-face temperatures above 1400° C. The thermal conductivity of these dense refractories at the high mean temperatures coupled with the rather thick walls and roofs that must be used, even when reduced by insulation, does not allow of more than perhaps 50° to 100° C. drop in temperature from the hot-face to a point 9 in. back, where insulation might appropriately begin. Bricks suitable for this purpose have been made in small quantities. In Table III Bricks Q and W are substantially sillimanite, developed from trials initially carried out by the British Refractories Research Association. Porous silica

TABLE III

SOME PROPERTIES OF BRITISH HOT-FACE INSULATING BRICKS

Brand letter	Bulk density, lb. per. cu. ft.	True porosity, per cent.	Temperature, ° C., at which in 2 hours reheating the linear shrinkage reaches :		Thermal conductivity B.Th.U./sq. ft./hour/°F./in. at mean temperatures of :			Cold crushing strength, lb. per. sq. in.	Modulus of rupture, lb. per sq. in.	Temperature, ° C., at which in 2 hours reheating under a load of 10 lb. per sq. in. the subsidence reaches:		Air permeability, C.G.S. Units (Range)	" Small prism " Spalling Index
			0·5%	1·0%	400° C.	500° C.	540° C.			1·0%	5·0%		
Z	33·2	80·0	1240	1270	1·60	1·73	1·78	180	—	—	1200	0·4 to 0·6	8
B	47	72	1240	1270	2·44	2·57	2·64	290	130	—	1200	2·7	> 17
G	51	70	1250	1280	2·48	2·56	2·64	660/390	370	1190	~ 1280	0·015	15
C	46·0	71·2	1260	1310	2·25	2·38	2·44	350	260	1210	~ 1280	0·7 to 1·1	5
D	46·7	70·9	1300	1350	2·28	2·42	2·49	600/330	240	1230	~ 1290	0·5 to 1·9	6
E	59	65	1290	1325	2·18	2·36	2·48	640/310	260	1225	> 1300	0·8	7
Y1	47·2	72·8	1320	1350	2·34	2·49	2·55	170	—	< 1200	—	3 to 7	15
T	54·5	68·0	1330	1360	2·50	2·58	2·62	630	—	1290	—	0·16 to 0·48	> 41
Q	63·9	65·9	1470	—	2·84	2·93	2·97	450	—	> 1300	—	0·5 to 1·1	8
W	66·1	64·2	1370	1415	3·06	3·12	3·15	520	—	1290	> 1300	0·12 to 0·21	14
N	73·0	56·0	1300	1320	3·70	3·95	4·05	300	—	—	—	0·8	> 20

bricks have been made suitable for use up to about 1500° C. During the next few years, it is expected that these and other types will be available, but at the moment the tremendous demand for hot-face insulating bricks hinders the launching of new brands. It is interesting to note that the American Society for Testing Materials classification includes bricks for use up to 1510° C., which may be as heavy as 60 lb. per cu. ft., and yet comply with the specification. Such bricks have been used in forging furnaces in America. A gas-fired test furnace at the Mellor Laboratories of the British Refractories Research Association, lined with porous sillimanite bricks made by the frothing process, has been used almost daily up to 1400° C. for four years without requiring attention.

An ingenious method of economising in the super-refractory materials, where slag erosion does not occur, is to combine the dense refractory lining and the backing up " hot-face " insulating brick into one unit. The author has been concerned in the development of this idea during the last seven years.

THE FUTURE

In modern times we have seen a number of natural products forced to compete with and then become supplanted by artificial equivalents or substitutes, e.g., washing soda and indigo. The substitute captures the market by a progressive reduction in the costs of production and by the opportunity its originators have of matching its properties to suit the call of the market. Anyone acquainted with the refractories industry will know the difficulties in cheapening production costs. One of the refractory manufacturer's directions of approach is, therefore, by artificial means so to improve the product that it gains acceptance over the customary type. The present demand for hot-face insulating bricks indicates that this has been done when the temperature on the furnace side is below 1250° C. When insulating bricks made from super-refractories are called for, the high raw material cost may allow these highly porous bricks to be made at a lower cost than the dense product, putting two advantages in the hands of manufacturers of insulating bricks, i.e., lower first cost and fuel-economy in use. The author anticipates steady infiltration of hot-face insulating bricks to positions at present occupied by common firebricks and further additions to the range of bricks offered, extending to higher temperatures the victory already won in the moderate temperature region.

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4. The Selection of Refractory Materials in Relation to Fuel Economy

By DR. G. R. RIGBY*

The present paper is concerned with the selection of refractory materials other than insulating products, and it will be shown how the properties of these materials can influence fuel requirements.

HEAT LOSSES IN REFRACTORY INSTALLATIONS

Various types of heat loss are encountered in practice.

(A) HEAT REQUIRED TO RAISE THE TEMPERATURE OF THE SETTING

Clearly, since heat is needed to bring the structure up to working temperature each time it has been allowed to cool, the longer the installation can be kept in continuous use, the less fuel is required for a given output. The former advantage of small intermittent units, that of being readily adjustable to trade conditions, can hardly have the same significance today in view of the great increases in the cost of labour and fuel.

(B) LOSSES BY CONVECTION AND RADIATION

These are determined by the quantity of heat flowing through the furnace walls. The thermal conductivity varies as shown in Table I. The wall thickness may be dictated by practical considerations of wear and strength. In addition to conduction through the wall, heat may be carried by transpiration of hot gases through the bricks due to differences of pressure. The permeability of a wall to gases has been shown to be 50 to 100 times greater than that of the bricks from which the wall was built. Due to permeability, the outer surface temperature of a blast furnace increased from an initial value of 75° F. to 108° F. after twelve months and then to 132° F. after three years, the corresponding heat losses per sq. ft. of surface per hour being 200, 370 and 495 B.Th.U. respectively. The fact that the permeability of brickwork to gases is largely due to joints is an argument in favour of monolithic structures.

(C) LOSSES DUE TO PRODUCTS OF COMBUSTION

This can be reduced by regeneration, but even so some 40–50 per cent. of the total heat input of an open-hearth furnace may be carried away by the waste gases leaving the regenerators.

(D) FURNACE DESIGN AND HEAT LOSS

Furnace design may have a considerable influence both on fuel economy and on the life of refractory materials. The combustion chamber must be sufficiently large to ensure that the fuel is burnt where it can be most effective, but without being too large so that its area is increased unnecessarily. The quality of the refractories constituting the ports or burner blocks so that they do not wear in use, is most important, as otherwise the flame direction may be changed ; water-cooled pipes are sometimes inserted to lower the temperature of the brick and so assist in maintaining the contour. Ill-fitting doors are an important source of heat loss. The refractory material round apertures can be rapidly burnt away by the hot gases and flame if the furnace works at a pressure, unless provision is made to protect it.

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* British Refractories Research Association.

TABLE I

THE PROPERTIES OF REFRACTORY MATERIALS

Type of refractory material	Bulk density, lb. per cu. ft.	Specific heat	Thermal conductivity, C.G.S. units	Refractoriness value, ° C.	Refractoriness under-load value	Reversible thermal expansion 20°–1000° C.	After contraction or expansion	True specific gravity
Hard-fired silica brick. SiO_2 = 95·5 per cent. CaO = 1·75 per cent.	100–110	0·2–0·3	0·002–0·003	1710	1680° C. at 50 lb./sq. in.	1·15 per cent. 20–1000° C. 1·00 per cent. 20–600° C.	+ 0·2 per cent. 2 hours at 1450° C.	2·32–2·35
Semi-silica brick containing sand. SiO_2 = 91 per cent. Al_2O_3 = 7 per cent.	115–120	0·2–0·3	0·002–0·003	1640	1550–1580° C. at 50 lb. sq. in.	0·62 per cent. 20–1000° C. 0·50 per cent. 20–600° C.	± 0·3 per cent. 2 hours at 1450° C.	2·60
Siliceous firebrick. Al_2O_3 = 25–30 per cent.	125	0·2–0·3	0·002–0·003	1620–1650	1380–1440° C. (28 lb./sq. in.)	0·60	± 0·75 per cent. 2 hours at 1400° C.	2·5–2·6
Aluminous firebrick. Al_2O_3 = 38–45 per cent.	125–130	0·2–0·25	0·002–0·003	1720–1750	1550–1620° C. (28 lb. sq. in.)	0·55	± 0·3 per cent. 2 hours at 1400° C.	2·6–2·7
Sillimanite brick. Al_2O_3 = 55–66 per cent.	140	0·25	0·003–0·004	1770–1820	1700° C. (28 lb./sq. in.)	0·55	± 0·1 per cent. 2 hours at 1400° C.	3·0
Fused alumina.	180	0·2–0·3	0·007–0·008	> 1800	1700° C.	0·79	nil at 1400° C.	3·8–4·0
Silicon Carbide. SiC = 85·90 per cent.	140–150	0·2–0·25	0·020–0·035	> 1800	> 1700° C.	0·48	nil at 1400° C.	3·0–3·2
Magnesite brick. MgO = 84–92 per cent.	160–170	0·2–0·3	0·012 (200° C.) 0·005 (1200° C.)	1800	1500–1630° C. (28 lb./sq. in.)	1·2	0·0–0·3 per cent. 2 hours at 1400° C.	3·5–3·6
Chrome-Magnesite brick. MgO = 40–60 per cent. Cr_2O_3 = 20–35 per cent.	180·190	0·2–0·3	0·004	> 1800	1600–1700° C. (28 lb./sq. in.)	0·80	± 0·3 per cent. 2 hours at 1400° C.	3·7–3·9

HEAT RESISTANT PROPERTIES OF REFRACTORY MATERIALS

(A) REFRACTORINESS VALUE

Refractories are heterogeneous, consisting of refractory grains surrounded by a less refractory matrix. In silica bricks, the matrix is largely glass interspersed with tridymite crystals. In fireclay brick, the refractory grains consist of mullite and silica (quartz and cristobalite), with less glass. The amount of glass in basic bricks is small since the liquid matrix almost completely crystallises on cooling. The glass begins to soften at a low temperature and the brick becomes distorted under pressure, e.g. at 700°–800° C. ; increase in the temperature increases the amount of glass. A steep temperature gradient in a brick helps it to stand up to high temperatures under pressure.

Silica bricks, unlike firebricks, are almost as refractory under an external load as they are when unstressed. The refractoriness value of a silica brick is 1690° to 1730° C., but unlike firebricks most silica bricks will withstand a load of 25 lb. per sq. in. at 1600° C. without serious deformation taking place, and even when failure occurs it is by shear rather than by viscous deformation. This enables silica bricks to be used with one face maintained at a temperature only 20° to 30° C. below that of the softening point of the brick. Silica is the usual material for the roofs of open-hearth and electric-arc furnaces and the temperature of the hot-face is 1650° to 1670° C. In acid steel furnaces silica bricks are used for the whole of the refractory superstructure.

In an attempt to improve the thermal efficiency of the open-hearth furnace attention has been given from time to time to the possibility of insulating the furnace roof, for which purpose vermiculite has been used. The roof bricks only retain their structural stability by means of the steep temperature gradient maintained through the roof which is usually some 12 to 15 in. thick. Insulation decreases this gradient, consequently the face of the brick wears back at an increased rate. Silica bricks also find application for the construction of the walls of gas retorts and coke ovens. Here the whole of the special blocks are at a temperature around 1350° C. and under these conditions deformation due to load is negligible, consequently the walls of the retorts can be made comparatively thin without endangering the stability of the structure.

The refractoriness value of basic bricks is considerably higher than that of fireclay or silica. The melting point of pure magnesia is 2800° C., but the minerals present in the matrix of such bricks usually have a much lower melting point, and under a load of 50 lb. per sq. in. most magnesite bricks fail by shear at a temperature around 1600° C. The sensitiveness of magnesite bricks to spalling considerably limits their usefulness and to overcome this the chrome magnesite brick has been developed. The coarse fraction of these bricks consists of chrome ore while the magnesite is added as fines, the weight ratio usually being about 7 : 3. In the fired brick the coarse grains consist of chrome ore which is a complex solid solution of a number of spinels all having melting points over 2000° C. The matrix consists largely of magnesium orthosilicates, forsterite and monticellite, together with excess free magnesia. A first quality chrome-magnesite brick has a softening point higher than 1700° C. under a load of 50 lb. per sq in. Naturally chrome-magnesite bricks find their most useful application in installations which are maintained at high temperature and require the formation of a basic slag for refining the metal. They are now generally used for the back wall and ports of basic open-hearth furnaces, and for the walls of basic electric-arc furnaces and copper-refining furnaces, while they have also given good results in rotary cement kilns. The heat capacity and thermal conductivity of basic bricks are about double those of silica bricks and firebricks, so one would imagine that substituting chrome-magnesite bricks for silica bricks would lower the thermal efficiency of the process although the margin of safety as regards refractoriness value is considerably increased. If it were not due to a peculiar failure which takes place when chrome-magnesite bricks absorb iron oxide, the all-basic open-hearth furnace would have materialised at a much quicker rate. There have been many attempts to utilise chrome-magnesite bricks in the roofs of open-hearth furnaces, but economic success has not always been attained. One advantage of the all-basic furnace is that steel can be refined at higher temperatures, but unless special precautions are taken this must result in higher heat losses through the furnace structure. There is no reason, however, why some measure of insulation should not be used in conjunction with a basic roof since the margin of safety as regards softening temperature is so much higher than with silica. Tentative steps have already been taken in this direction, the Germans having used 2 in. of powdered magnesite as an external coating for their basic roofs.

(B) VOLUME EXPANSIONS AND CONTRACTIONS

When refractory materials are fired certain chemical reactions take place depending on the temperature of firing and degree of soaking. However, these reactions do not reach equilibrium and J. W. Mellor pointed out many years ago that the study of refractory materials was essentially a study of arrested chemical reactions. When a refractory brick is built into a setting which may be subjected to a certain temperature over a very long period of time these chemical reactions may go a stage nearer completion, and in doing so alter the volume of the brick. Firebricks, in general, tend to contract while silica bricks usually show an increase in volume. It is important in many cases to try to assess the change in volume which might be expected from refractory materials in service, and the after-contraction or after-expansion test has been designed for this purpose. It is obviously undesirable to have excessive shrinkage of bricks as the joints then tend to open up, slags and gases can penetrate behind the face of the bricks and corrosion is increased. If there is a positive pressure in the furnace, hot gases and even flame are forced out through the joints, resulting in a marked heat loss. On the other hand, draughting conditions result in large amounts of cold air being sucked into the combustion chamber and the thermal efficiency is again reduced. From this angle the quality of the jointing cement is also of importance. A firebrick jointing cement must have workability, and to obtain this a plastic material such as clay or bentonite must be added. Clay materials shrink on firing, and if this shrinkage is sufficiently pronounced it may result in cracking or breaking away of the jointing material resulting in a large increase in the permeability of the brickwork. Attempts have been made to develop cements with a minimum clay content, the contractile nature of which is offset by admixing it with a large proportion of non-plastic material which tends to be expansile when heated. It is obviously very desirable to have the walls of gas retorts, coke ovens and muffle chambers generally as gas-tight as possible.

Most fired fireclay materials tend to contract in service, particularly if they are subjected to temperatures higher than the initial firing temperature they received in the kiln. Certain fireclays, however, show an expansile effect over a definite range of temperature, which may result in the brick undergoing an increase in volume. Various theories have been suggested to explain this phenomenon, which in certain cases is known to be a bloating effect. Deliberate advantage is sometimes taken of this property and bricks tending to bloat at high temperatures have been used for lining steel ladles. Under the action of the molten steel the brickwork tightens up, the joints compress and slag penetration via the joints is reduced.

Unlike fireclay materials silica refractories tend to increase in volume during service owing to the conversion of any residual quartz to tridymite or cristobalite, both of which have specific gravities lower than quartz. It is important that silica refractories used for gas retorts should be almost entirely converted to tridymite or cristobalite before being built into a setting. Properties such as the true specific gravity and after-expansion at 1450° C. are utilised to assess the amount of free quartz remaining in the material.

The reversible thermal expansion of magnesite and silica refractories between room temperature and 1400° C. is double that of fireclay products and in building a setting of these materials spaces have to be left between various bricks to accommodate this expansion. With silica roofs which are often set dry, compressed cardboard, felting or wood strips are placed at certain positions so that when these have burnt out the bricks can expand into the spaces which they have occupied. Steel sheets or steel mesh are usually placed between various courses of chrome and chrome-magnesite bricks. The necessity of providing for expansion joints sometimes makes it a difficult matter to obtain tight structures.

(C) THERMAL SHOCK AND SPALLING RESISTANCE

Under certain conditions mechanical stresses can be set up in refractory structures due to inequalities in heat treatment which may be so severe as to crack the brickwork. The term spalling or dunting is frequently applied to such types of failure, but several different kinds of spalling failures can be recognised. In the first place, mechanical stresses can be induced due to different parts of a setting being heated at different rates. Similarly with individual bricks in a setting, heat is applied to only one face of the brick, temperature variations occur resulting in different parts of the brick expanding at different rates and the brick is in a state of stress. If these stresses exceed a certain value, depending on the mechanical properties of the brick, they are relieved by the brick cracking. It is obvious that spalling due to temperature gradients exceeding a certain value is connected with such properties of the material as thermal expansion, temperature diffusivity, modulus of elasticity and ultimate tensile or shear strength. Resistance to thermal shock, as this type of spalling is sometimes called, varies widely among different refractory materials, largely owing to the differences in thermal expansion. Silica bricks are often quoted as being abnormally sensitive to thermal shock, which indeed they are over the temperature range 20° to 600° C., the reversible thermal expansion being about 1·2 per cent. What is perhaps not sufficiently appreciated is that above 800° C. the reversible expansion of silica bricks is almost nil, consequently sudden variations over the range 800° to 1650° C. can occur without any danger to a silica installation. Such violent drops in temperature actually take place when, for example, a coke oven is discharged. Since fireclay refractory materials exhibit plastic flow at temperatures below 1000° C. it has been argued that fireclay installations have a high resistance to spalling above 900° C. as any strains can then be relieved by plastic flow. However, a fireclay brick cooled suddenly to a low temperature from, say, 1200° C. will spall more readily than one cooled suddenly from 900° C. as in the former case the temperature gradients through the brick will be steeper.

Magnesite bricks have a high but regular reversible thermal expansion, the coefficient being about 13×10^{-6}. This means that magnesite bricks are sensitive to thermal shock at all temperatures and for this reason they cannot be used successfully in exposed positions in the open-hearth furnace. They are therefore relegated to the sub-hearth of the furnace protected by a thick layer of sintered or rammed dolomite. Magnesite bricks are used successfully, however, as a lining in inactive metal mixers which maintain a reservoir of pig iron at a temperature between 1150° to 1250° C. for feeding Bessemer converters. In such mixers the inner magnesite lining is backed by firebrick followed by insulation, consequently the temperature gradient through the magnesite wall is low and the strains in the brick are insufficient to cause spalling.

Another type of spalling is manifested when the surface of a brick is altered during service thereby acquiring characteristics different from the remainder of the brick. In most installations only one face of a brick is exposed to optimum temperature and slagging conditions and for a certain, often well-defined distance behind this face the brick undergoes a marked alteration in properties. This results in a plane of weakness developing some distance behind and parallel to the hot face and strains set up due to temperature variations tend to produce surface spalling which shows itself by the hot face flaking off. Surface spalling is sometimes experienced with bricks in combustion flues of blast-furnace stoves where alkali vapour is present. The alkali vapour tends to vitrify the surface layers which then differ in characteristics from the remainder of the brick. The effect of zonal alteration in silica products is well exemplified by bricks taken from open-hearth roofs. The silica at the hot face is present entirely as cristobalite ; behind this is a tridymite zone, then comes a pale yellow zone where the matrix has collected after retreating into the brick from the hot face and finally behind this is the unaltered brick. Great care has to be taken in heating up an old silica roof otherwise the whole of the cristobalite zone will spall and detach itself from the roof.

Merely subjecting refractory materials to a prolonged series of heating and cooling cycles may reduce their strength without any obvious signs of cracking taking place. This progressive embrittlement is usually ascribed to the slow crystallisation of the glassy matrix which results in the bricks becoming friable, the surface being readily abraded away.

(D) THE THERMAL PROPERTIES OF REFRACTORY MATERIALS IN RELATION TO CONSTRUCTION

The inherent sources of failure in refractory installations can obviously be enhanced or reduced, depending on the construction of the furnace chamber. In this respect suspended roofs and walls may have much to recommend them over against sprung roofs and solid masonry walls. In such methods of construction the refractory blocks, which are of special shapes, are individually hung from or keyed to a steel framework. This method of construction is claimed to minimise the strains which are set up when a solid mass of brickwork is heated from one face, thereby reducing the possibility of structural spalling. In addition, cracked bricks are prevented from falling out and the furnace chamber is rendered more gas-tight, thus improving thermal efficiency. The load on individual bricks is reduced in a suspended arch as against a sprung arch, since the weight is taken by the steel hangers, consequently distortion of the bricks due to softening under load is minimised. Finally, one portion of a suspended roof can safely be renewed without any danger to the stability of the remainder of the roof. Suspended construction is often associated with boiler installations, and suspended roofs have been used with marked success on all types of reheating furnaces. The German design for the basic roof of an open-hearth furnace consists in suspending the transverse ribs which form every fifth course, while the four courses between the ribs are sprung from the skewback channel, the tension of which can be varied by means of coiled springs.

THE DISINTEGRATION OF REFRACTORY MATERIALS BY SLAGS AND GASES

It is very seldom that refractory materials are called upon to resist the effects of temperature alone, generally they have to withstand, in addition, the action of slagging agents either in the solid, liquid or vapour phase, or they may be exposed to the disintegrating action of certain gases.

The rate of slag erosion depends on many factors, the chemical composition of the slag and refractories, the temperature, the furnace atmosphere, the physical characteristics of the slag and its reaction products, the texture of the refractory, etc. It is not surprising, therefore, that slag attack can only be assessed with difficulty in the laboratory and a variety of tests have been developed, none of which is entirely satisfactory. Refractory materials vary widely in their ability to withstand the action of specific slags as illustrated by the following examples.

(A) RESISTANCE OF REFRACTORY MATERIALS TO IRON OXIDE SLAGS

Iron oxide figures as a constituent of most slags, in certain instances refractory materials have to withstand the action of slags consisting almost entirely of iron oxide, for example, the hearths of open-hearth furnaces, soaking pits and all kinds of reheating furnaces. The only oxide of iron which is stable in contact with the metal is ferrous oxide, FeO, so that where the slag is in contact with iron, ferrous oxide is the slagging agent. All fireclay and alumino-silicate refractories have poor resistance against ferrous oxide ; mullite, which is generally present in such materials, is decomposed in the presence of ferrous oxide, hercynite and fayalite being formed. Fayalite forms low melting point eutectics with silica and alumina, the addition of 20 per cent. of ferrous oxide to most fireclay bricks being sufficient to lower the refractoriness value to about 1300° C. Even sillimanite products have their refractoriness value lowered very rapidly by ferrous oxide addition. Pure alumina is much more resistant since combination occurs between alumina and ferrous oxide resulting in the formation of hercynite, which itself has a high melting point (over 1750° C.). Ferrous oxide and magnesia form a complete series of solid solutions and since the melting point of magnesia is so high, it can take about twice its own weight of ferrous oxide into solid solution before the melting point of the mixture falls below the normal working temperature of the open-hearth furnace 1680° C. Magnesite is the refractory with the highest resistance to ferrous oxide slags, but unfortunately its use is limited owing to its sensitiveness to thermal spalling. Silica refractories have a higher resistance to ferrous oxide slags than might be imagined at first sight in view of the low melting point eutectic between fayalite and silica at about 1,170° C. This is because there is a region of liquid immiscibility extending from 96 per cent. silica and 4 per cent. ferrous oxide to 57 per cent. silica and 43 per cent. ferrous oxide where the liquidus temperature remains constant at 1650° C. Before the refractoriness value of silica bricks is lowered below 1400° C. it is necessary for the material to absorb about its own weight of ferrous oxide. This is important in connection with the slagging which occurs in the lower portions of gas retorts where the reducing atmosphere maintains the iron slags in the ferrous condition. Used silica bricks from such retorts contain appreciable amounts of fayalite associated with the slagged face.

(B) RESISTANCE TO IRON OXIDE SLAGS AND LIME

In the open-hearth furnace above the metal level, boiler installations, etc., the slags consist of a mixture of iron oxide and lime, the iron oxide being oxidised to magnetite or to a solid solution of magnetite with ferric oxide. Reactions between magnetite and silica appear to be much slower than between ferrous oxide and silica, fireclay materials also appear to be able to resist the action of magnetite more readily than ferrous oxide. Chrome-magnesite bricks are often used to resist the action of iron oxide slags in the open-hearth furnace. These bricks have a much higher spalling resistance than magnesite and they can be used in exposed positions such as the ports and back wall of the furnace. Since magnetite is a spinel it will enter into solid solution with the chrome grains, but this solid solution formation is accompanied by a peculiar growth of the grains which expands the face of the brick, introducing a zone of weakness behind the face which may then spall off, exhibiting a fresh surface to further attack. Firebricks are used to resist the action of lime-bearing slags in the blast furnace and in lime kilns, anorthite being a common reaction product between slag and brick.

(C) RESISTANCE TO ALKALI SLAGS

Alkali vapours are prevalent in the blast furnace and hot-blast stoves, gas retorts, by-product ovens and glass-melting furnaces. At high temperatures, with fireclay materials, vitrification of the surface occurs with the formation of alkali alumino-silicates. At lower temperatures fireclay refractories absorb alkali chloride vapour, exhibiting a peculiar growth which can be simulated in the laboratory by hanging suitable specimens in the vapour of the salt. Sillimanite refractories have a high resistance to alkali slags and are extensively used in glass tank furnaces.

(D) DISINTEGRATION BY CARBON MONOXIDE

This peculiar type of disintegration is most serious in the linings of blast furnaces where the refractories come in contact with fairly high percentages of carbon monoxide. This gas in the temperature range 400° to 600° C. tends to decompose into carbon dioxide and carbon. The decomposition is very slow unless catalysed by metallic iron which may be present in the brick lining having been formed by the reduction of localised iron-bearing minerals present in the fireclay. These active nuclei form centres for carbon deposition which may ultimately disrupt the brick. It is not uncommon for blast-furnace linings at the end of a campaign, to consist of a hard vitrified face, a course of unchanged brickwork next to the casing, and between the two a mass of broken brickwork and carbon due to extensive disintegration having taken place in that part of the lining where the temperature gradient is between 400° and 600° C. Hydrocarbon gases can show similar disintegration but the optimum temperature is higher than with carbon monoxide.

THE DURABILITY OF REFRACTORY MATERIALS IN RELATION TO THERMAL EFFICIENCY

Sufficient examples have been quoted to indicate that the conditions under which refractory materials are used vary very widely. In the open-hearth furnace we have a combination of high temperature and excessive slagging conditions, whereas at the other extreme are the refractories used for lining tunnel kilns firing heavy clay goods to a temperature of *circa* 1000° C., slag attack being negligible. The factor of safety in metallurgical furnaces is often so small that insulation has not been attempted on a serious scale. On the other hand, where the properties of the refractories are more than adequate for the service conditions, insulation has been used and has had a marked effect on thermal efficiency.

It is obvious that it is impracticable to apply insulation to those installations where the stability of the refractory is only maintained by ensuring a steep temperature gradient through the wall or lining. Reducing this temperature gradient by a backing of insulation would raise the mean temperature of the hot-face material and promote the penetration of fluid slags further into the brickwork. The result would be a more rapid wearing back of the hot face. If heat transmission through the walls and roof of such furnaces is to be reduced the most promising step is to develop better refractories, i.e. hot-face materials with a higher resistance to slag attack and an increased stability under load at high temperatures. The present type of refractory materials might be improved in their performance ; for example, in America a so-called super-duty silica brick has been developed in which great attention has been paid to reducing the amounts of fluxing oxides, alumina and alkalis to negligible proportions (a total of less than 0·4 per cent.). It has been claimed that this brick gives increased performance in steel furnaces, copper furnaces and glass tank furnaces over the normal run of silica materials. Much research work has been carried out to try to reduce the bursting expansion which takes place when chrome-magnesite bricks absorb magnetite. If this bursting expansion could be reduced basic open-hearth roofs would become a more attractive proposition ; at present basic roofs which have been tried in this country have failed due to the spalling away of the slagged face during week-end shut-downs.

A promising line which is receiving increasing attention is the development of materials with very high melting points for special positions where conditions are severe. Bricks made of pure sintered alumina (m.p. 2050° C.) and pure sintered magnesia (m.p. 2800° C.) are now on the market, but their high price has militated against extensive trials being made. Fused mullite blocks (m.p. 1810° C.) have been used fairly extensively in glass tank furnaces and good performances have been reported. Fused spinel (m.p. 2135° C.) has been made on the Continent for manufacture into bricks, but there are little data regarding their properties and performance. Other materials which deserve a close study owing to their high melting points are zircon, zirconia, andalusite, sillimanite, chromic oxide, titania, beryllia, the rare earth oxides, also synthetic carbides and nitrides.

REFRACTORY MATERIALS FOR REGENERATORS AND RECUPERATORS

The temperature and slagging conditions in regenerator chambers and stoves are not so severe as in the furnace chamber proper so that more attention can be focussed on those properties of the refractory fillings which are important regarding heat transfer. The quantity of heat abstracted by the checker filling from the outgoing gases is dependent on : (1) the nature and extent of the brick surface ; (2) the extent and design of the flue system ; (3) the heat capacity of the brickwork ; (4) the thermal conductivity and (5) the period of reversal. It is evident that it is the surface layers of the brickwork in checker fillings which undergo the maximum variations in temperature, and are responsible for most of the heat storage and subsequent regeneration. The total surface of brickwork which can be employed per given volume is obviously related to the dimensions of the flues which can be tolerated and this in turn is dependent on the amount of dust carried in the outgoing gases. Blast-furnace stoves heated by dirty blast-furnace gas have to be built with a more open checker work than stoves heated by clean gas where the dust has been removed. In the latter case complicated shapes have been designed for stove fillings, all of which are destined to give a long and sinuous path to the gas as it passes through the stove, thereby exposing the maximum surface of brickwork. It is obvious that much more efficient regeneration can be obtained with stoves operating on clean gas. In the open-hearth furnace the regenerator chamber is preceded by a slag pocket where some of the dust is deposited to reduce choking and slagging in the checkers. The common filling for open-hearth checkers is a second quality silica brick for the top five to ten courses, followed by fireclay or semi-silica bricks for the bottom courses. In recent years there has been a trend, however, to replace the silica by a high alumina fireclay brick. The checker work in blast-furnace stoves, on the other hand, is fireclay but there has been an increasing tendency for the more aluminous fireclay materials to be used as they possess higher refractoriness-under-load properties and increased resistance to alkali vapours which are present in small amounts even in the cleaned gas.

The specific heats of silica and firebricks are very similar, the value at room temperature being about 0·20, but this increases with increasing temperature until at 1400° C. the value rises to 0·32. Since heat capacity is an important criterion there is obviously a case for using bricks of high bulk density or low porosity. An average figure for apparent porosity of silica bricks is between 22 and 28 per cent., while the bulk density, which depends both on the grading and percentage of unconverted quartz present, can vary between 1·55 and 1·87 g. per ml. Firebricks have been made with apparent porosities as low as 11 per cent. and bulk densities of the order of 2·28, but these are exceptional and the average porosity of fireclay checker bricks is 18 to 25 per cent. The rate at which heat diffuses from the surface into the interior of the brick is measured by the temperature diffusivity of the material which is obtained by dividing the thermal conductivity by the heat capacity. The ideal filling for checkers should have high diffusivity, but this can only be obtained at the expense of heat capacity, so in practice a compromise must be effected. It is doubtful whether too much emphasis need be placed on the thermal properties of the brickwork since the rate of heat transfer between the surface of the brick and the air is a controlling factor which depends to a large extent on the nature of the brick surface. The surface of checker bricks rapidly changes in use since slag is deposited on them comparatively rapidly. In the open-hearth furnace the top courses of checkers have to be renewed after about 26 weeks because they are severely slagged away. Experiments have shown that glazing the surface of the brick appreciably reduces the rate of heat intake of the material so that glazed bricks are not suitable for re-use in checkers. Further work has indicated that used checker bricks which have not been glazed have a higher heat capacity than unused bricks so that these can be satisfactorily salvaged without any loss of efficiency.

The thermal efficiencies of checkers can be improved by insulating the downtakes and the chamber itself to minimise cooling of the products of combustion before they reach the checker chamber. There is also a wide field for investigation on the design of checkers to give optimum turbulence to the hot gases consistent with keeping the flues sufficiently wide to stop blockage by dust and slag deposition. The utilisation of bricks having higher thermal conductivity and bulk density should result in better heat transfer. Care should be taken with the checker walls to reduce air infiltration and risk of connection between the gas and air chambers. Many open-hearth regenerators are encased in independent steel plating to reduce leakages through the chamber walls. Most furnaces reverse on a time schedule, but it is obviously preferable to reverse on a temperature schedule which will safeguard the checkerwork from damage due to the temperature rising above a desirable maximum. This point is appreciated in some plants where temperatures in the open-hearth regenerator chambers are continuously recorded by means of radiation pyrometers. It is also customary to watch the temperatures of hot-blast stoves by inserting a thermocouple in the dome. If the temperature of the checkerwork in the stove is uncontrolled, vitrification and shrinkage sets in, being aggravated by the alkali vapours present in the blast-furnace gas. Instances have been recorded of the checkerwork in stoves shrinking by several feet, while intensive vitrification of the surface of the brickwork has led to spalling and flaking away of the face.

CONCLUSIONS

It can broadly be stated that thermal efficiency due to choice of refractory decreases markedly as the operating conditions become more severe, partly because insulation cannot be applied without the risk of the hot face refractory material showing increased wear and giving uneconomic life. This at once suggests the development of refractory materials having greater heat and slag resistance and includes the possibility of the development of super-refractories.

Much research and plant investigation will have to be undertaken before it can be shown that the high cost of such materials is justified by increased service life and higher thermal efficiency.

5. Concentrated Combustion

By DR. C. M. WALTER

INTRODUCTION

The term " concentrated combustion " must be regarded as relative since there have been in use for many years burners and burner systems giving degrees of concentration of heat that depended on the design and the available temperature head. These burners used gas at ordinary supply pressure with air under pressure, or pre-mixed gas and air under pressure. This communication refers to burners and burner systems which have been developed both here and in America during the last few years to increase the available temperature head to the maximum possible, and so to increase the rate of heat transfer.

The burner systems to which these remarks apply include the C.C. Burner which has been developed in Birmingham in the Industrial Heating Section of the City of Birmingham Gas Department and other systems which have been developed by the Selas Corporation of America, for high-temperature operations.

DESIDERATA

The main objects to be achieved from these recent designs may be summarised as follows :—

(1) To obtain the maximum possible transfer of heat from the flame or hot gases to the work to be heated.

(2) To effect this transfer of heat at the maximum rate possible.

(3) To enable the dimensions of the chamber in which the work is heated to be reduced to a minimum, with a consequent reduction in wall losses.

(4) To enable, in certain special applications, the furnace structure to be completely eliminated, and replaced by a burner system which transfers the heat direct to the work.

METHODS EMPLOYED TO ACHIEVE THESE OBJECTS IN THE CASE OF THE C.C. BURNER

In order to obtain the maximum rate of heat transfer, the heat flow potential must be a maximum, with the result that the flame temperature must approach the theoretical maximum figure for the particular fuel employed. To enable these conditions to be fulfilled it has been necessary :—

(*a*) To provide as far as possible an air/gas mixture of the proportions necessary for the obtaining of the maximum flame temperature.

(*b*) To ensure, as far as possible, that the air/gas ratio required should remain constant over a reasonable range of consumption to allow for a reasonable " turn-down ".

(*c*) To increase the mixture velocity for a given air pressure, in order to confine the combustion to the smallest possible space and thereby increase the heat flow potential to a maximum.

CONSTRUCTIONAL DETAILS OF C.C. BURNER

The C.C. is a multiple burner, built up of a number of small units each of which is separately controllable as regards gas, air and mixture. By this method of construction, it has been found possible to obtain a more flexible system, eliminating the possibilities of lighting-back when operating under " turn-down " conditions, and at the same time enabling the combustion of the mixture to be confined to the tunnel itself over a wide range of gas consumption.

Reference to the American designs indicate that these generally operate on a pre-mixed gas and air mixture under pressure, the mixture being supplied to each individual outlet from a common manifold.

APPLICATIONS

The heating operations to which the C.C. Burner has already been applied cover a very wide range and include forging, metal melting, billet heating, tube heating, brazing, glass melting, salt-bath heating, continuous bar heating and heat treatment of steel.

CONCLUSIONS

From the above it will be observed that the advantages to be gained by the employment of the C.C. Burner for the heating operations mentioned are :—

(1) Increased rate of production.

(2) Improved efficiencies in certain applications, and consequent reduction in fuel consumption.

(3) Reduced thermal capacity of furnace structure owing to reduction in general dimensions, and a consequent reduction in wall losses.

(4) The complete elimination of the furnace structure in certain special applications.

It is anticipated that the development work which is being continued will lead to further improvements both in the design of the burner and in its method of application, resulting in an extended field of use and further fuel economies.

6. Factors Controlling Furnace Efficiency in the Steel Industry

By H. C. ARMSTRONG

Mr. Armstrong maintained that firms engaged in furnace building should give their chief draughtsmen greater opportunities for seeing the results of their designs in practical operation. Many furnaces appeared to be of excellent design when on the drawing board, but relied too much on the furnace operator being highly skilled and fuel economy minded. Complicated controls were frequently not correctly operated in practice, the furnaceman finding he could get results by comparatively crude handling. Valves must be made easily accessible right at the side or front of a furnace or they might be neglected. Everything should be as handy and easy for the furnaceman as for a motor-car driver. Further, the design should be such that every control, etc., provided must be worked correctly and short circuiting of such made impossible. Attention was also required to giving more positive indication of the opening of a damper. Most dampers could be closed considerably without affecting the draught so that the operator wrongly believed that he was reducing the effect of the chimney.

If a furnace worked equally well without touching all the controls or valves provided, they were obviously unnecessary " extras " and should not be there. Practical observation by the designer would be the best way of bringing home to him these points which, though possibly insignificant to some people, were of very real account in obtaining the best furnace efficiency. A return visit should also be paid to all furnaces at least a year after installation. Alterations were sometimes made by the user and found to be advantageous. It might be a long time before the furnace builder was informed of this.

The time had come to alter entirely one's ideas of furnaces. The furnace of the future must be a " machine " in the fullest sense of the word. There was no reason why a furnace should not be viewed from this angle and made as perfect as any precision machine in a workshop. The " heating box " of the past, and also the present unfortunately, must go. Production managers must get rid of the idea that the same furnace would do a multiplicity of different jobs. Furnaces should be more nearly designed to the needs even if it meant having more furnaces of different size or temperature capacity in the same shop. There was always a tendency to instal a furnace to cover all possible requirements and for the furnace to be too big for 80 per cent. or even more of the daily work. Furnace builders were under a difficulty in offering the fullest controls, especially automatic, since it had been the custom to regard these as extras with added costs in the tender. The builders should offer the complete design as one whole. Surely they were sufficiently certain of their ground to know what they offered was correct. Very little criticism was offered by the purchaser of a machine tool which was expected to be complete and up-to-date in every way. This should equally well hold in the case of a new furnace. Air/fuel ratio, furnace pressure and automatic temperature control were some of the needs of the furnace machine he hoped to see in the future.

7. Aerodynamics in Relation to Furnaces

By DR. A. H. LECKIE

Up to the present it has been possible to apply only the simplest fundamentals of aerodynamics to furnaces as the combination of turbulent movement of gases, together with more or less complex combustion reactions, makes more detailed theoretical treatment very difficult. The word aerodynamics used in connection with furnaces simply refers to the calculation, investigation and control of the flow of gases in furnaces.

The furnace designer needs to consider two broad divisions :—

(1) The movement of gases to and from the furnace.
(2) The behaviour of gases in the furnace chamber itself.

Study of (1) is required to ensure that the necessary quantities of gas and air can reach the furnace chamber, taking into account the available supply pressure, and that the stack draught is sufficient to exhaust the products of combustion together with any infiltered air.

Study of (2) is necessary to ensure efficient combustion and heat transfer to the stock, to minimise damage to the refractories and to eliminate waste due to excess air and infiltration of air.

The chief field of study is large furnaces of the reversing regenerative type. Small furnaces are usually fired by clean gas which is available at a pressure of several inches w.g. and positive pressure air is easy to apply. Most of the pressure drop occurs in straightforward pipelines and valves, and the numerous formulæ available in standard reference books are applicable. It is relatively easy to secure efficient combustion as properly designed burners and pre-mixed air may be used.

It is a different story with the large reversing regenerative furnaces used in the steel and glass industries. Owing to the high temperatures at which these furnaces work and the consequent thermal and structural stresses, the brickwork cannot be made entirely gas-tight, with the result that the permissible pressures and draughts are low, sometimes 1 inch w.g. or less. For this reason pressure drops of a few hundredths of 1 inch w.g. are quite sufficient to alter the gas flow conditions appreciably.

Conditions in the furnace working chamber are also complicated by the necessity, in a reversing furnace, of making the same set of ports serve for both ingoing and outgoing gases. It is therefore not possible to select the type of port which will give the most efficient combustion as such ports cannot handle large volumes of waste gases.

FLOW OF GASES TO AND FROM THE FURNACE

In considering the movement of gases to and from the furnace working chamber, the designer has to calculate whether the available pressure is sufficient to overcome the resistance of the various bends and changes of section on the way to the working chamber, taking into account any buoyancy effect brought about by changes in vertical height. To enter here into a discussion of the methods of doing this would be superfluous as the subject is discussed fully in several standard text-books of furnace technology, and a review of the most up-to-date methods of calculation is given in the Ministry's publication " The Efficient Use of Fuel " (pp. 173–197).

In spite of the existence of such published data, there is still a regrettable tendency for a new installation to be designed on the empirical basis of some other plant which has worked well without due consideration being given to individual conditions. For instance it is still quite common practice to design furnace passages on the basis of square feet per ton of capacity. This is all right for a start, but the resulting design must always be checked by calculation of the pressure balance for both ingoing and outgoing systems, by the methods mentioned. It must be remembered, however, that the calculation of pressure losses through a furnace system involves the use of coefficients which are only approximate so that precise calculation to a fraction of an inch w.g. is not possible. Nevertheless, such calculations are essential to eliminate risk of disappointment after the furnace is built.

BEHAVIOUR OF GASES IN THE FURNACE WORKING CHAMBER

It may be said at the outset that early combustion of gas and air is a prime desirability in the existing types of furnace ; this has been demonstrated theoretically by Thring and Reber (J. Inst. Fuel Wartime Bulletin 1945, p. 120) and practically by Chesters and Thring (Iron and Steel Institute Special Report No. 37) and by our own work on a small-scale furnace. Admittedly, securing of the required furnace atmosphere may demand combustion conditions far removed from the optimum, but even in such circumstances it may well be better to work with correct combustion to secure fuel economy, and to control the atmosphere in other ways.

When preheated gas and air are used in a reversing furnace gas ports which permit of pre-mixing of the air and gas to any extent are not practicable. The flame is therefore a pure " diffusion flame " in which the mixing of gas and air depends on the mutual turbulence of the gas and air streams. It is always difficult to get sufficiently rapid mixing in the confined space of the furnace chamber, particularly when the flame path is relatively short (as in glass tanks). The theory of the mixing of gas and air in diffusion flames is complex, but some very useful practical papers on the subject are (1) the series of papers published in 1937 by K. Rummel (Archiv. fur das Eisenhuttenwesen, vols. 10 & 11) and (2) a paper presented to the Institution of Mechanical Engineers in the same year by R. F. Davis (Proc. Inst. Mech. Eng., 1937, 137, 11).

Rummel found that good mixing depended on:

(*a*) a large difference in the velocities of gas and air.
(*b*) high velocities of gas and air.
(*c*) excess air.

These findings are not so simple to translate into practice, as (*a*) and (*b*) are obviously incompatible to a large extent, and with regard to (*c*) it is not at all certain whether any benefit gained from improved mixing following the use of excess air is not more than offset by the increased waste-gas losses. Recent experiments with a small-scale furnace carried out by the British Iron & Steel Research Association (J. Iron & Steel Institute, 1947, **155,** 392) have indicated that, on balance, excess air is undesirable ; this may seem confirming the obvious, but this point has hitherto been by no means clear with regard to open-hearth melting furnaces ; so much depends on the mixing conditions in individual furnaces. If design is bad, excess air may well be necessary not only to ensure proper combustion, but to keep the roof cool.

R. F. Davis discussed primarily the behaviour of jets of air in boiler practice but his reasoning is equally applicable to furnace flames of the diffusion type. His paper gives simple formulæ indicating the size of, and flow in a jet at various points along the axis, and by using these formulæ, and by making certain simplifying assumptions it may be shown that in a producer gas flame of the type encountered in regenerative furnaces, mixing should be theoretically complete between 5 or 6 port diameters from the port nose (though this does not necessarily mean that combustion will be complete within this distance).

The validity of some of these conclusions has been tested by the British Iron & Steel Research Association in the experimental furnace referred to above. The findings of both Rummel and Davis have, in the main, been confirmed, but their application to production furnaces lead to some interesting conclusions. In the experimental furnace the best results so far obtained have been with high velocity air (i.e. very small air ports) when using port angles similar to those used in normal furnaces. This corresponds to Rummel's condition (*b*) above. In a reversing furnace such ports are not practicable since large volumes of waste gases have to be handled in the same ports. The next best results were obtained with a small gas port and a large air port (Rummel's condition (*a*) above). Intermediate sizes of air port in the experimental furnace gave poor results and in a reversing furnace it therefore appears desirable from the mixing aspect to use as small a gas port as possible with a large air port. The size of the gas port is limited by the pressure which is available to drive the necessary quantity of gas through the port, as calculated in the furnace pressure balance. If it is possible to make the gas and air enter at nearly 90° to each other, as in the Maerz type of open-hearth furnace, the velocities of gas and air are less important.

Calculations along the lines indicated by Davis suggest that if the available pressure permits of a gas port area A, it may be better to obtain this by the use of two ports of area A/2 rather than by a single port. The use of a number of gas ports is customary in glass furnaces (for reasons not only connected with gas and air mixing) but in steel-melting furnaces the use of two or more gas ports, although giving satisfactory combustion, has not found favour owing to structural difficulties, but these may in future be overcome by water cooling or by the use of super-refractories.

Nevertheless, the whole study of the subject of port design confirms the view that the non-reversing furnace, obtaining its preheat either by recuperators or by the use of " hot valves ", offers the best solution of the problem and the research programme of the British Iron & Steel Research Association includes active work on this.

Whilst the attainment of rapid mixing of gas and air seems to depend (in normal designs of reversing regenerative furnace) on the use of a small gas port in conjunction with a large air port, other factors besides mixing may enter into the design of the furnace. The factors governing selection of gas port size are complex and contradictory ; some of these are briefly outlined below.

(i) *Gas pressure available.*—Small gas ports demand high gas pressure. High gas pressure may involve excessive blowing rates in the gas producer, and with many present-day producer coals, high blast pressures are impracticable.

(ii) *Turbulence and mixing.*—Small ports (for a given gas rate) lead to improved mixing of gas and air, and more rapid combustion.

(iii) *Volume of flame.*—A large port gives a greater radiating surface and a " thicker " flame so that the rate of heat release is increased.

(iv) *Speed through the furnace or " stay-time ".*—A small port presumably leads to a shorter " stay-time ", and this " stay-time " may not be long enough to permit of adequate heat release. Little is known about this, but its importance has been stressed by practical melters.

(v) *Convection.*—Small ports and the resulting increased velocity appear to result in improved heat transfer by convection. Theoretically, convection should play only a very small part compared with radiation, owing to the high temperature of the open-hearth furnace, but in practice " convection " appears to be quite important ; actually the apparent importance of this may not be due to true effects, but to combustion catalysed on the surface.

In the foregoing, nothing has been said about the shape of the port block, apart from the individual port sizes. This is because very little is known about the true influence of port shape—in practice very widely differing designs (such as the Maerz and Venturi open-hearth furnaces) give satisfactory results and each has its champions among operators. There is obviously an immense field for research, both to obtain guidance on the question of port shape, and on factors such as (i)–(v) above. A recent large-scale trial carried out by the United Steel Companies, Ltd., in conjunction with the British Coal Utilisation Research Association (Chesters and Thring, *loc. cit.*), the results of which are now being studied, promises the elucidation of many points, but much remains to be done. At present, the best advice to give to the furnace designer regarding these controversial points is to build his furnace with proper regard for the elementary principles of aerodynamics outlined above, but to make the structure sufficiently flexible to permit a certain amount of experimental work during normal operation. For instance, if there is doubt about the minimum size of the gas port which is permissible, any permanent feature such as a water-cooled casing, should be designed on the large side ; further adjustments can be made by the insertion of a brick lining according to performance in day-to-day operation.

After the gas and air have left the ports and become mixed, the path of the flame across the furnace is of great importance in order to secure the maximum heat transfer to the stock with the minimum risk of damage to the roof. Here the most elementary law of aerodynamics comes into play—the fact that hot gases tend to rise. The furnace atmosphere is always cooler than the flame, and to correct the inevitable tendency of the flame to rise, the ingoing ports are given a downward inclination. Nevertheless, any further cooling of the furnace atmosphere by infiltered air is most undesirable, not only because of the direct thermal losses, but because cool air has a natural tendency to enter at the bottom of the working chamber where it causes the flame to rise still further, thus diminishing heat transfer to the stock and endangering the roof. Therefore all furnaces should be operated with as high an internal pressure in the working chamber as is practicable—this is normally governed by the amount of flame which escapes from furnace openings. It is not always appreciated that the escape of flame involves far less thermal loss than that brought about by the air infiltration which results from increasing the draught to reduce flame escape to a small amount (see J. Inst. Fuel, April, 1943). The increased efficiency brought about by working at high pressures has been demonstrated most emphatically in the experimental work both of B.I.S.R.A. and of United Steel Co. with B.C.U.R.A.

This leads to emphasis upon the necessity for more exact control of operation, and the extended use of instruments. The better the aerodynamic design of a furnace the more sensitive it is to bad operation ; indeed a well-designed furnace, if badly operated, will give poorer fuel consumption figures than a bad furnace skilfully operated. With the present practical limitations of design, far more can be done to improve fuel consumption by extending control by instruments and by training the operators and encouraging alertness in watching the controls, than by modifications in design unaccompanied by attention to the operation. Therefore, a final point for attention by present furnace designers is the ensuring that the furnace layout is suitable for the incorporation of all the necessary control instruments. It is particularly essential to include in the layout suitable straight lengths in the ingoing air and gas ducts to permit of the installation of gas and air metering orifices. Even crude producer gas (provided the temperature is above the tar deposition point) can be satisfactorily metered with modern equipment.

Finally, it must be said that industry as a whole is becoming increasingly alive to the importance of a study of aerodynamics in relation to furnaces. The British Iron & Steel Research Association has a very active Fuel Committee in its Plant Engineering Division, and the programme of work of this committee, together with that of the Steelmaking Division Committees and of the Physics Department, includes a large amount of research on the many problems which, as shown above, still require solution. In addition, the individual works themselves are devoting a considerable part of the resources of their own Research Departments to similar work.

8. Factors Controlling Furnace Efficiency in the Glass Industry

By H. L. CROOK

Mr. Crook began by briefly describing the furnaces used in the glass industry (c.f. " The Efficient Use of Fuel ", chapter XIX). The process was continuous with a maximum temperature around 1500° C. A typical furnace might have an area of 500 sq. ft. The essence of successful operation was that the furnace should melt glass and deliver it to a second compartment in the furnace homogeneous, free from bubbles and at a temperature suitable for machine operation.

With furnaces fired by producer gas, the efficiency of the producer was all-important. The efficiency of the furnace was dictated by the manner in which heat was used at the furnace hearth combined with the extent to which waste heat was recovered. It was essential that the minimum quantity of waste gas should be discharged from the furnace at the lowest practicable temperature and with the minimum of heat losses from the outer surfaces of the furnace. Many possible future improvements were dependent upon the availability of better refractories, but in general to secure the optimum conditions described it was necessary (*a*) to design ports and combustion spaces to give complete combustion before the gases left the chamber, (*b*) to set up conditions most favourable to heat transfer to the stock so as to complete the operation with the minimum of heat, (*c*) to use insulation and other means to reduce the loss from the furnace walls, and (*d*) operate the combustion with as high a percentage of CO_2 in the flue gases as possible.

Investigation of the temperature and composition of the waste gases in the exit ports had shown striking variations; in some the gases were leaving partly unburnt, while in others there was considerable excess air. There was room for improvement in the design of ports to give better mixing ; this design must be a compromise to allow for varying quantities of gas to accommodate varying loads and, in cross-fired furnaces, to allow of the same port being used for both inlet and exit. The design for oil firing would require to be different from that for gas firing.

The method of feeding the batch varied considerably between manual and mechanical feeding in small piles and as a continuous ribbon. A recent development was a suspended end wall capable of vertical adjustment with batch feeding in a continuous blanket. All these devices were designed to melt the maximum quantities of glass and so increase the overall efficiency. Bound up with this was the control of temperature down the length of the tank by proportioning the size of the ports and by using more ports than the conventional number of three or four. There was a radical difference between the transfer of heat from producer-gas flames and from liquid-fuel flames.

The insulation of furnace crowns was now practised extensively but better refractories were required. There was need for a refractory high-temperature insulating brick at commercial prices for hot-face insulation in the superstructure. Better refractories for the tank walls and elsewhere could reduce the heat now lost through the need for forced cooling. There were signs that such bricks might soon become available.

Glass furnaces were nearly always operated by manual control. Great advances had been made recently in metering raw producer gas and in instrument design and these introduced the possibility of fully automatic control of pressures, temperatures and reversal. There was still need for robust and reliable instruments to operate under bottle-house conditions of heat, vibration and dirt.

Waste-heat recovery was important. Much work had been done on the physical problems connected with the design of the regenerators, but the theoretical results had not been translated into practice. One of the chief problems was slagging due to alkaline dust and vapours carried over and there was need here also for highly resistant refractories at commercial prices. Consideration should be given to the installation of waste-heat boilers.

Furnaces should be designed of such a size that they could operate on maximum loading. Electric melting was a probable development of the future.

9. Insulation from the Manufacturer's Standpoint

By A. E. HUBBARD

It has been stated that if all furnaces were insulated to the optimum extent, the fuel consumption of those furnaces would be reduced by 20 per cent. And, since a very large proportion of the fuel used in industry is consumed in furnaces of one type or another, such insulation would produce a saving of considerably more than 10 per cent. of industrial fuel.

The function of thermal insulation has been understood for a very long time (e.g. clothing), and its application in steam engineering followed quickly upon the introduction of steam to industry, but, although furnaces had been used for the production of heat as an industrial tool long before the use of steam became general, no attempt, except in a few isolated cases, was made in this country to economise in fuel by the rational use of insulation until about twenty years ago.

Shortly after the 1914–18 war, an American firm which had successfully developed the industrial uses of insulation in the States, decided to develop the British market, and, accordingly, placed before British furnace users details of the diatomaceous materials which they produced, together with information about the fuel saving which had been effected in various industries.

About that time the first serious attempts were being made to dispel the long held idea that British coal was an inexhaustible source of cheap heat ; but it was typical of the lack of heed paid to that very sound propaganda, that insulation received scant consideration, and its adoption was an extremely slow process. Even when the hot-face limit of 800–850° C., imposed by the properties of diatomaceous materials, was raised to 1250–1350° C., by the introduction of high-temperature insulating materials, progress remained slow up to the outbreak of war in 1939.

Owing to the lack of general appreciation of the value of insulation, the industry had not been able to develop to the extent to which it should have done ; with the result that when, in an attempt to solve some of the many problems of war time production, furnace users wished to make more general use of insulation, the output was not sufficient to cope with the demand, especially in the field of high temperature insulation ; furthermore, some manufacturers had, soon after war broke out, taken the opportunity offered by the considerably increased demand for fireclay and other refractory materials to convert plant previously used for the production of high-temperature insulating materials to the production of such refractories.

The result was that, even at a time when the necessity for the utmost fuel economy existed, many furnaces had to be built without insulation, and these furnaces, together with the very large number of uninsulated or partially insulated furnaces already in existence, were instrumental in wasting more than two million tons of coal each year.

In view of the particular importance of fuel economy at the present time, it is of interest to consider some of the reasons for the very slow appreciation of insulation. It is not suggested that the types of mental attitude described under the first three headings below are in any way unique to insulation, for they have constituted an inexcusable bar to progress in many fields.

First there is that inherent suspicion, which seems to exist in the mind of the great majority of works men, of the integrity of a seller. Despite the fact that the case for insulation was put forward with data on the characteristics of the material, and illustrated by examples of what had actually been done on furnaces of similar type working under similar conditions, the works man concentrated on looking for the catch, and even when calculations were submitted, based on the particular type of fuel and on the actual furnace structure that he was using, he still could not bring himself to believe that the statements made could be within reasonable bounds of the truth. Despite the logic of the arguments, and the rational nature of the figures employed, he asked for guarantees. Even though, when the desired guarantee was discussed in detail, his common sense showed him that to arrive at any basis of a guarantee which would be legal and binding, was quite impossible.

The method of approach was one not previously used in that field, but even so there was no excuse for the general air of suspicion which was so apparent, and if the works men had concentrated more on deciding whether a scheme submitted had a reasonable chance of success, and then tried to get it adopted, very large quantities of coal would have been saved already.

The second factor of resistance was initial cost—it is always a source of amazement that so many otherwise intelligent business men will still buy the material or piece of plant which is cheapest in first cost, despite the fact that the extra running and maintenance costs may, in a very few years, have amounted to several times the original cost. It was demonstrated repeatedly that the cost of insulation involved in a given furnace would save its cost, in fuel alone, in anything from 6–18 months, but still furnace users preferred to save a few hundred pounds in first cost notwithstanding the fact that the amount saved was wasted many times over during the life of the furnace—such figures become more striking with the introduction of high-temperature insulation which made possible the replacement of the ordinary firebrick lining by insulating material, on a furnace operating up to, say, 1200° C. In addition to the saving of fuel by the reduction of conduction through the furnace structure the heat stored in the lining was considerably reduced and consequently, in the case of intermittent furnaces, the fuel used each cycle for the heating of the lining was reduced accordingly ; quite apart from the ancillary advantages of speed of attainment of working heat, etc.

The third factor was to some extent tied up with the first. This was the determination, once it had been decided to use insulation, to prove that it was no good. Instead of adopting the attitude that having bought insulation everything possible should be done to get the best out of it, it was found in so many cases that the co-operation of the furnaceman was not enlisted with the result that the crown of the fire-box was overheated, or that after a campaign it was found that no fuel saving had been made. Common sense indicated that, if heat were prevented from passing through the structure, a given heat could be obtained in the furnace chamber, without the necessity for developing such an intense heat in the firebox as had previously been required ; a little time spent with the furnaceman would have resulted in economy instead of an early repair. Similarly, if the damper were not operated rationally, it would be possible to pull up the chimney a great deal of the heat which would otherwise have been saved. Instead of encouraging the furnaceman to produce the maximum saving, he was allowed to use his own methods of showing the management that the insulating bricks were no good.

A fourth factor which was encountered in high-temperature furnaces and in the combustion zone of medium-temperature furnaces, was the effect of insulation on the refractory lining. Obviously there are some positions, e.g. the crown of an open-hearth furnace, where the use of insulation is not at present an economic proposition because the value of the fuel saved would not be justified by the shortening of the life of the roof. Incidently, the use of the expression " at present " should be noted, for in due course materials will be available which in addition to making possible the demand of the steel maker for that extra 100° C. in the bath, will have a thermal conductivity appreciably lower than that of the materials now used.

It has often been argued that, by its effect in raising to a considerable extent the mean temperature of the refractory lining, insulation shortens the life of the furnace. The fallacy of this argument lies in the fact that it is based on using the same type of refractory as had been used before insulation was incorporated in the furnace structure. Had a suitable high-duty refractory been used, the full advantage of insulation would have been obtained, together with an actual lengthening of the life of the furnace, thus showing a further saving due to the reduction of shut-down losses.

It is not altogether surprising that very few British manufacturers attempted to enter such a difficult market, but it was fortunate that a few had the courage to do so. And when they realised the necessity for insulating materials with a higher temperature range than that of the diatomaceous material originally available, they carried out the research required to produce such material.

The effect of high-temperature insulation is two-fold : first, since in a large number of high-temperature furnaces it can be used as the lining, it makes possible, by virtue of its low thermal conductivity a backing of diatomaceous material of still lower conductivity within the same or a less thickness than was previously occupied by firebrick alone. Second, as its thermal capacity is considerably lower than that of firebrick, the amount of heat required to bring the lining up to working heat is considerably less, thus effecting a further saving of fuel as well as of time. This latter effect increases in importance as the time-cycle of the furnace decreases.

Much work on the application of high-temperature insulation to the walls of regenerators still remains to be done, for it is obvious, since the thickness of the inner layer of wall which can play any part in the process of regeneration is a relatively small percentage of the total wall thickness, that the incorporation of insulation behind that thickness will not only reduce the quantity of unavailable heat in the wall, but will also permit of a considerable saving of time in the heating up of the structure. Also, by its effect in raising to a very considerable extent the mean temperature of the thin refractory lining, the heat potential will be increased, so increasing to some degree the efficiency of regeneration.

In the development of high-temperature insulation having a porosity of 60–70 per cent., it was found that, in order to obtain stability at a working temperature in the region of 1350° C. it was necessary to use material which was more refractory and which had a shorter softening range than was required for the production of a firebrick which would be stable under the same conditions. Moreover, since the high temperature insulation was to be the lining of the furnace, it must be set in a mortar giving a strong ceramic bond in order to ensure the mechanical strength of the wall. The insulating value of such a mortar is of necessity very much lower than that of the brick, consequently in order to obtain the highest over-all insulating value, the brick must have the highest degree of accuracy both of size and of shape. The attainment of these characteristics was a costly process, but the product amply justified its cost even before the war when its value to users was based on coal at 10*s.* to 15*s.* per ton. The cost of such a product today is considerably higher than pre-war, but, when calculated on the basis of coal at 40*s.* per ton, its economic value is found to have increased considerably more than its cost, quite apart from its essential function in an all-out drive for fuel economy.

The importance of the price factor lies in the fact that up to now the development of high-temperature insulating materials has been seriously hampered by the instability of the market. Instead of being able to design and instal plant which would ensure the most efficient and economical production to cater for a steady demand, the manufacturer has had to utilise plant which, in the event of the demand for that product dropping off, could easily be turned over to other production, or alternatively, he has set a very small target production, which did not involve the installation of special plant. The foregoing, together with a variety of other factors, combined to make the production of high-temperature insulation before the war not only difficult but also unremunerative.

There never was any doubt about the necessity for insulation, and it was perfectly obvious that in due course the demand would be such as to make it a remunerative business in which losses sustained during the early period would be made good, but the situation so discouraged some short-sighted manufacturers that they decided to cut their losses and cease production at a time when that production was most needed, and it was unfortunate that there was no authority to insist that such production was maintained. Today, the production of high-temperature insulation becomes not merely a question of developing a potential market but of catering for one of the fundamental essentials to fuel economy.

In evaluating an insulating material it is necessary to have certain characteristic data such as thermal conductivity, cold crushing strength, under-load refractoriness, specific heat, apparent density, etc., and it is essential that the manufacturer should make such data available with a degree of accuracy that will enable the user to accept that data without question, and so avoid the wasting of the time of the users' research physicists in checking manufacturers' data. A standard method of determining thermal conductivity is necessary.

The furnace designer requires also to know the overall conductivity of a furnace structure, and this involves two factors : the conductivity of brickwork when set in mortars and the conductivity of a composite, jointed wall, consisting of refractory backed by insulation, or of two or more types of insulation.

The apparatus in use in this country only enables relatively small pieces of material to be tested : it can only deal with one material at a time and the test cannot be conducted at a hot-face temperature of more than 1000° C. giving a mean temperature in the region of 500° C. But when high-temperature insulating bricks are installed in a furnace operating at, say, 1350° C., and are backed by diatomaceous insulation, they may be operating at a mean temperature of 1000° C. or more and their conductivity under working conditions may be very different from their conductivity at a mean temperature of 500° C. Apparatus can be built capable of giving the information referred to, but it is far too expensive to be installed by an individual manufacturer. It should be installed at a central research station, e.g. the B.R.R.A., and the cost shared between the manufacturers and the users.

10. Recuperation in Relation to Furnaces

By C. H. WILLIAMS

During the past few months, papers have been read before the Institute of Fuel dealing with heat recovery in all its aspects. In the short time available, I can only touch on some of the wider points raised in these papers and the discussions on them.

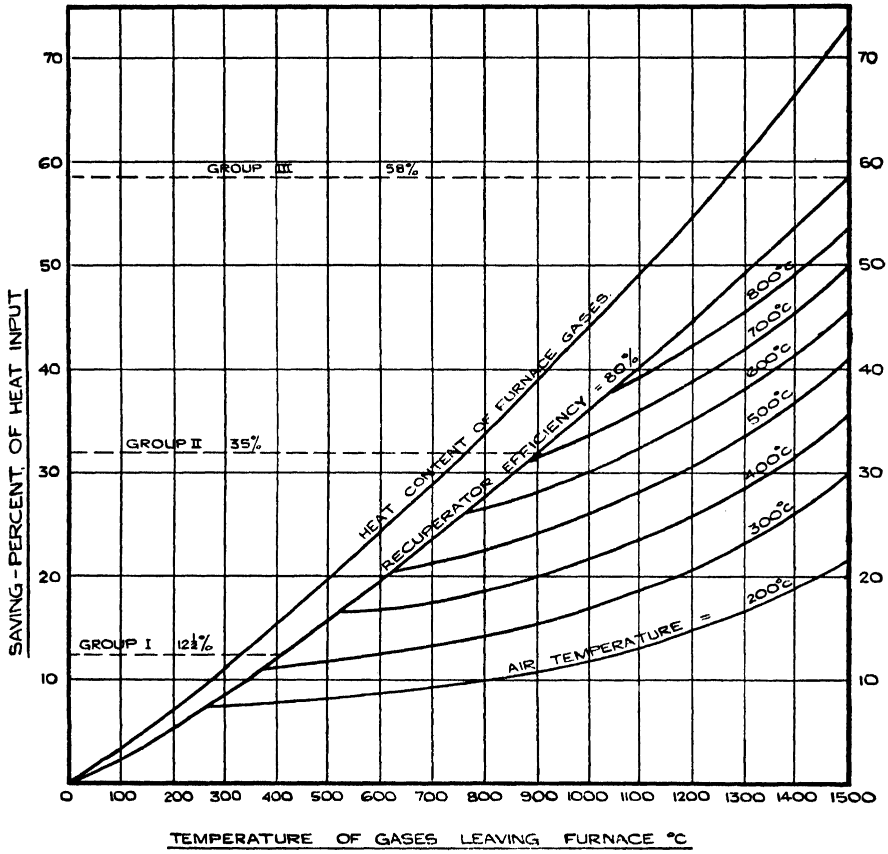

FIG. 24.—Possible Saving by Recuperation of the Combustion Air, for Coke-Oven Gas.

Recuperation can almost invariably be made to pay for itself if the installation is carefully planned. Fig. 24 shows the savings possible in three different groups of furnaces : the lower-temperature group covering the heat-treatment of light alloys and tempering of steel ; the medium-temperature group comprising various heat-treatments of steels and non-ferrous metals ; the high-temperature group, including rolling and forging of steels, glass melting, etc.

Even with as low a waste gas temperature as 400° C. a saving of the fuel input under certain conditions can be realised. The range of temperature between 500° C. and 950° C. offers the best scope in that the recuperator can be economically designed to withstand the working conditions with only low maintenance, and the thermal return can be as high as 25 per cent. to 30 per cent. of the fuel input. Except in certain cases, all furnaces which are to be in fairly frequent use for reasonably long periods should be built with a recuperator.

Recuperation or regeneration, as opposed to, say, waste-heat boilers, is thermodynamically the correct method of heat recovery in that it raises the potential head of the system. That is, it returns heat to the system at the highest temperature level where it can most effectively be utilised. This is manifested in either a lower fuel consumption or in a greater output, either of which represents an economy in fuel.

There are, of course, a few special processes where, by using preheated air, flame temperature is increased above that allowable, but these are so few that they need not be enlarged upon. Direct coal or coke fired furnaces with grates or stokers must also be excepted, as any serious preheat above, say, 150° C. gives rise to clinker trouble, also to much firebar and tuyere maintenance unless the air is used above the fire as secondary air, in which case the quantity is severely limited. There are other furnaces where the products of combustion are led off at a number of isolated points, and it is not practicable or economical to instal recuperators. There are, additionally, such furnaces as those of the continuous conveyor type, where the products of combustion escape below the charge and discharge doors and around the conveyors and thus mingle with the atmosphere below lead-off hoods. The temperature is thus lowered below a worth-while figure. Such furnaces are usually highly efficient by virtue of their continuous method of operation, the heat recovery by this means, i.e. preheating of charge, consisting of high quality of heat-treatment and saving in manpower.

Dealing now with some particulars of metallic recuperator design, the greatest heat transfer is usually obtained by the smallest confining space. Thus it is better to use small, smooth tubes than to use large tubes with internal corebusters. " Needles " or fins represent a compromise since they are an integral part of the tube, and the heat picked up is conducted directly to the air. On the waste gas side, however, it is often preferable that the tubes should be smooth to avoid dust deposition and to allow easy cleaning. Although much has been said about greater gas radiation from increased depths of the gases, the transfer of heat by gaseous radiation, with the layer thicknesses normally available in recuperators, can only represent at medium temperatures a small proportion of the total heat transfer. Convection, then, and not radiation, should be the basis of recuperator design, except in the high-temperature ranges.

Failure of metallic recuperators follows overheating of the metallic partition between the air and the waste gas. This partition can be kept at its minimum temperature by ensuring that the rate of heat transfer on the air side under all conditions exceeds that on the gas side. Thus the partition will always be nearer in temperature to the air than to the gas. Other safeguards are the use of diluting air in the waste gases—providing these are fully combusted—and the use of a by-pass. Both systems need careful regulation and, usually, instrumentation, and are not, of course, conducive to efficiency of air preheat.

Variations in direction of flow of air and gases are also used, such as leading a proportion of the coldest air through the hottest pass, or a higher and constant rate of flow through this. Protection of the metal by a layer of refractory is employed ; this achieves the aim of protecting the metal, but obviously lowers the air preheat or requires more elements for the same degree of preheat.

Another cause of failure of metallic recuperators is attack by sulphurous acid during the initial heating stages or during lay-off periods when the metal is cold enough to condense the sulphur dioxide in the water vapour from the gases. This usually occurs during the heating-up stages with a cold furnace. This same remark applies, as far as efficiency is concerned, to tar and soot deposition. Provision should be made to by-pass the gases directly to the chimney until the furnace is sufficiently warm to ensure the gases leaving well above their dewpoints.

Refractory recuperators are more commonly used for high-temperature furnaces and stand up to the arduous service and abuse more easily than the metal type. The objection that they take more time to heat up is of little consequence in furnaces which are in almost continuous operation, and their heat storage is often an advantage : even on low-temperature work, providing it is continuous, they are still often favoured. Their use, however, nearly always entails deeper and more expensive foundations.

The refractory types for high-temperature furnaces are slowly but quite definitely replacing regenerators except, up to the present day, in such cases as the open-hearth steel furnace and the like, where exceptionally high temperatures are concerned. The advantages of designing the burners and waste gas offtakes according to the definite requirements of the furnace, and not the requirements of the regenerators, yield far superior results to those obtained by the compromise of regenerative furnaces. For temperatures up to 1450° C. refractory recuperators have proved themselves over a period of many years. The statement that a refractory recuperator always leaks is unjustified by our own experience. Tests taken on a glass furnace and on soaking pits which had been in operation for a considerable time showed that 92 per cent. to 95 per cent. of the air input to the recuperator arrived at the burners. The air and waste gas pressures are largely in balance, and the effect of porosity and small hair cracks is negligible. The essential joints between the recuperator blocks (i.e., those joints separating air from waste gases) are, at least in one design, horizontal and maintained tight by gravity even with movement of the blocks caused by expansion and contraction. Of course, if the recuperator is not correctly designed and constructed, very large leakages can occur.

Refractory recuperators have, for the most part, been installed to supply air at natural draught—occasionally they are blown at a very low pressure : any attempt to use any other than low pressure leads to leakage. Use has, therefore, been made quite extensively of air fans between the recuperator and the burners, giving a resultant hot air pressure of 2 in., 3 in. and 4 in. w.g. This allows of correct distribution to a number of burners or banks of burners, also of metering of air, thus obtaining the many benefits of completely automatic control. Such fans have to handle the air at preheat temperature, and I know of many instances of year-by-year reliability at air temperatures of up to 600° C. It must be emphasised that these fans deal with air temperatures only, and not any mean temperature between that of air and waste gas. The use of these fans maintains the desirable balance of pressures of air and waste gases in the recuperator.

I conclude by stating that the science and practice of recuperation, whether by refractory or metal, is at a high and reliable level and has been fully justified by savings over many years.

Much thought is being given to the subject and research is constantly taking place both in regard to materials and to design. Higher efficiencies, together with lower costs, will be the outcome whether in one or the other type, or in a marriage between the two either in series or in parallel.

11. Furnace Design in the Non-Ferrous Metal Industry

By F. C. ASHEN

Most of the furnace equipment in the non-ferrous metals industry is old. The industry itself is old and there has been a continuity of old practices for over two hundred years. It is therefore not surprising that many old furnaces are functioning as effective production units to-day and are under the fire of criticism for being thermally inefficient. Necessity did not force the adoption of regeneration or recuperation in order to obtain high temperatures, as in the steel trade, and what little has been done with fairly recent designs of furnaces is only a token tribute to the practice.

Thermal efficiencies certainly leave much to be desired and furnace output performances have also been outpaced by the development of faster machine processes to whose production schedule they are tied. The need for closer control of metallurgical effects and surface finishes is also tending to outmode them and the trade must look to the application of up-to-date knowledge to meet present-day and future needs.

We must exclude electric furnaces from the low thermal efficiency class, but we must, however, recognise that the low conversion efficiency of coal to electricity reduces the over-all efficiency of electricity as a heat source to approximately one-fifth of the direct efficiency of application. Fortunately, the check to the adoption of electric furnace has not come before a standard of excellence of design has been set, to be emulated by other furnaces using other fuels.

The fuels are used in a large cross-section of the industry in furnaces in the following proportions :—

	Per cent.
Coal and coke	50
Electricity for casting	22½
Electricity for annealing	9½
Town gas	10½
Fuel oil and creosote/pitch	7½

Producer gas, of which only a small amount is used, is included in the coal figure. Furnaces represent 45 per cent. of the total fuel consumption.

Furnaces can be broadly sub-divided according to the direct source of heat energy used in them. In the following, this classification is adopted with a brief appraisement of the position. A general comment on operators is that labour is being continually skimmed of intelligence and the up-grading of men leaves the least adaptable type for furnace operation. The supposition that instrumentation in its present stage of application can replace intelligent labour is largely responsible for this retrograde trend.

ELECTRIC FURNACES

(A) LOW-FREQUENCY MELTING FURNACES

Design good. Operation good. A normal direct thermal efficiency of 80 per cent. can be obtained. The 1,000 lb. furnaces have been found to be most efficient. Standby losses can be heavy and need eliminating ; this can partly be done by allowing the metal forming the secondary loop to freeze. The quality of production, tied to payment rates to operators, is the controlling factor for ensuring continuous efficient working. This necessitates the brass furnace being rebuilt when it becomes too slow to earn the standard rate.

(B) RIBBON RESISTOR ANNEALING FURNACES

Design good. Operation good to indifferent. Normal direct thermal efficiencies of 80 per cent. can be obtained. Logging of furnace performance and establishing a unit-per-ton figure for a working target is essential to maintain efficient operation.

Many variations of forced convection-flow furnaces give a more efficient heat transfer, but losses are increased, which levels the balance of efficiency. Design then becomes a factor for consideration.

(C) SALT BATHS

Design good, up to the limited arrangement of covers. Operation bad. Normal direct thermal efficiencies are as low as 30 per cent. Low throughputs, salt carry-over, radiation losses from badly fitting covers, and idle periods are unavoidable losses with normal usage. Reduction of standby temperature is the only economy practice that can be adopted. Logging of the bath performance is essential to keep a check indication of when it may be possible to concentrate production in fewer baths.

TOWN GAS FURNACES

(A) PREHEATING FURNACES

Design poor. Operation poor. Normal efficiencies for continuous furnaces of 30 per cent. would be above average. The design often precludes efficient operation. The striving for uniform heating in the combined combustion and charge chamber, by the various expedients of delayed combustion, is detrimental to proper combustion control, and proper furnace trimming can only be done by an expert. With various types of blast burners, the lack of precision in manufacture and uncertain flow characteristics of the valves, makes precise settings almost impossible. Damper arrangements are too crude and flues are so proportioned that the critical range of operation is too small a fraction of the full range. Air recuperation is more fanciful than real, the heat pick-up being negligible while often flue gas infilters from burnt recuperator tubes and leaking refractories into the combustion air, and persists for a long time before discovery.

(B) ANNEALING FURNACES

Design poor. Operation poor. Burners are usually of the atmospheric type with the secondary air under the influence of flue pull. There is nothing precise about the appliances or their functioning and proper control is almost impossible. The muffle types suffer structurally from reversible expansions and contractions and necessity will force the adoption of direct firing, with closely controlled combustion gases and greater simplicity of design.

(C) SALT BATHS

What can be said about equipment possessing such inherent low efficiencies ? If they are necessary evils, the closest attention must be paid to limiting the gas rates for maximum conditions of throughputs, secondary air adjustment and flue damper setting. Temperature recorders are a vital necessity, and a close check on each shift's gas consumption must be kept by the operators themselves. Heating and cooling rates must be known to enable economies to be effected by partial closing down during standby periods.

PRODUCER GAS FURNACES

(A) PREHEATING FURNACES ; (B) REHEATING FURNACES ; (C) ANNEALING FURNACES

These three types can be discussed together with the general comment that the criticism directed to town gas furnaces is equally applicable. Consequently, burners only will be here discussed. Poor combustion conditions advertise themselves by a characteristic smell and the toxic effects of escaping fumes. This leads to the use of considerable excess of secondary air and consequent waste. Burner arrangements and flame instability are the root causes of the trouble. Many burners are of the blast type with no primary air but swirling or parallel-flow secondary air. Now that we know something about blow-off phenomena it is possible to replace them with a precision made injector of capacity 1,000 cu. ft. per hour, giving a fully aerated flame, quite stable through a turn-down range of 6 to 1, with much better applicational efficiency, and self-adjusting to the fluctuations of pressure which are often unavoidable with producer gas distribution.

COAL-FIRED AND COKE-FIRED FURNACES

(A) MELTING FURNACES

Design : Lack of recuperation must place all types in the " bad " category and with efficiencies ranging from 6 per cent. for pit-fired to 18 per cent. for the larger reverberatory melting furnaces with good operation. Something must be done on the design side. Stoker firing might help, but in the old locations of the industry where labour has not been on the move, the highly developed skill in firing large refineries does not leave much margin for saving even with a mechanical-stoker replacement, on the present size of furnace.

(B) PREHEATING AND (C) REHEATING FURNACES

These two can be considered together and here again lack of a recuperative system condemns the design. Advanced technique of heat transfer must replace the old idea of a flame-swept hearth, and provide a better thermal tool, quicker in operation and more easily controlled.

(D) ANNEALING FURNACES

Of the various types, those which are fired by underfeed stokers and have good load recuperation can be considered good in design and operation, but there are some crude types which the war has kept in commission. The semi-gas-producer type can be excellent in design but suffers from lack of skilled operators remaining on the job.

PULVERISED FUEL FURNACES

In melting furnaces, conversions from solid fuel firing to pulverised fuel has not given large savings. A complete revision of shift working and output rates is essential to obtain the advantages of the higher rates of heat release. Recuperation is also needed.

OIL AND CREOSOTE/PITCH

(A) MELTING FURNACES

The comments regarding operational schedules with respect to P.F. firing are applicable to the reverberatory bath type to which oil firing has been applied, but very considerable advantages can be obtained with a rotary type of melting chamber, which, by virtue of the close confines of firing speeds up the time cycle. Production demands are the controlling factor for its continuous operation. Heat recuperation from flue gases having the highest temperatures of any process in the industry offers considerable scope.

(B) PREHEATING FURNACES

Applicational efficiency of oil and pitch firing to the small types of furnace is not good. The very high temperatures obtained in the combustion chambers cannot be efficiently transferred to the working hearth which cannot safely work at too high a temperature. Where direct firing into the charge chamber has been possible, the highly incandescent combustion characteristics of creosote/pitch have compensated for its lower calorific value and it has matched oil in fuel per ton output.

INSTRUMENTATION

In what has been said so far, instrumentation, or the lack of it, has not had a prominent mention as a controlling factor for ensuring furnace efficiency. This is not an oversight.

The introduction of control equipment has too often tended to appear to the man on the job, and this includes some production managers, as something to supersede a lifetime's experience and expert judgment. Even with a welcomed adoption it splits the responsibility for the success of thermal treatments. For instrumentation to become an integrated factor of furnace equipment control, it is essential for the instrument man to realise that his nerve centre is only a thermocouple point, and what the controller and recorder can do is only relative and perhaps not consistently so, with other things happening in equally vital parts of the furnace.

The instrument technician must play a more important part as we develop the push-button type of equipment and there is an urgent need for the type of man who can combine his function with general furnace work and have a knowledge of and be in full sympathy with all the difficulties encountered with thermal treatments. Instrumentation does not afford the facility of making use of less skilled labour as is often claimed. On the statistical aspect, it is necessary to check furnace performances at short intervals, but correct recording of fuel consumption and production throughputs are dependent on having individual metering for gas, electricity, and oil consumptions, and sufficient clerical staff to compile necessary fuel and production collations. It is not always possible to maintain a system of recording, unless it is interlinked with departmental routine for other purposes.

To conclude, it is my opinion that if there were no further advances made in the elucidation of combustion phenomena, heat transfer knowledge and instrumentation, we could, by the combination of knowledge and experience now available, building with the right materials, having controls simple in function, and making recuperation integral with the furnace operation, have furnaces which would leave little to be desired.

12. Remarks on Electric Furnaces

By A. GLYNNE LOBLEY, M.Sc., A.M.I.E.E.

One of the main features of the electric furnace is that the heat can be generated exactly where it is required and can be controlled with great accuracy.

No air is required for combustion nor flues for waste gases, and loss of heat can be reduced by efficient insulation. It is, in fact, true to say that the use of heavy insulation in the early designs of electric furnaces was an example followed to some extent by designers of fuel-fired furnaces, but in the latter case there was not the same proportional increase in efficiency as there was still a heavy loss of heat in the flue gases. (Up to 24 in. of insulation was used in electric furnaces at a time when fuel furnace makers thought 4½ in. was something wonderful.)

It follows that if insulating materials are adequately used, together with a sound design of doors and other parts which are vulnerable from the point of view of heat loss, little further can be done to increase the gross efficiency.

The net efficiency, or economy, depends on the amount of dead-weight which has to be heated in addition to the charge and much has been done and still can be done by using methods which reduce or eliminate these losses. It is, for various reasons, usually more possible to make such improvements with electric furnaces than it is with other types. Heat exchange methods are also sometimes possible and can materially increase the economy.

At the same time, it is obvious that however efficient the furnace is, it can be operated in a wasteful way, as for instance, by underloading or by leaving it switched on but out of use for long periods. With common sense, much of this can be readily avoided, but due to the low standby losses it is, in any case, not a very serious matter with electric furnaces. The fact that careless operation is not so disastrous to fuel economy as it is with fuel-fired furnaces, is an important advantage of electric furnaces.

Avoidance of heavy loads at peak hours may be even more important than fuel economy and for this reason it may be desirable to maintain the furnace at temperature rather than shut down at night, since the latter course involves a full load demand on starting up in the morning. Time switches can also be used to ensure the heating-up being at a period of low demand. Even during hours of work it is in some cases possible to link batch furnaces together, making use of their heat storage capacity so that the furnaces are not taking the full load simultaneously. In this way excessive peaks can be avoided and a high load factor obtained.

In certain processes electric furnaces are practically essential, but mostly they have been installed in competition with other types.

The decision as to type, ultimately one of cost, rests on a number of factors of which the direct cost of heat is only one, others being relative labour costs, the effect on previous or subsequent processes, working conditions, quality of output, general adaptability, capital cost, and so on.

Today, the important consideration is fuel economy, and judged on that basis a different choice would often be made. For instance, an electric furnace usually involves a much lower consumption of coal than does a solid fuel fired furnace. Even in those cases where the running costs of the solid fuel fired furnace are lower owing to the low heat losses, or standby consumption, the electric furnace compares especially favourably where the ratio of mass heated *in unit time to volume is low*, i.e. where the charge is light or where the period *of treatment is long* even where the charge is heavy.

New methods of high-frequency induction heating offer very high economy *where only part of the article requires to be heated, such as the end of* a bar or even a thin surface layer.

A few examples of the energy consumption of electric furnaces may be of interest.

(1) *Carburising.*—With batch electric furnaces and the work in pots, the consumption per gross ton ranges from 340 kWh to 540 kWh for case thicknesses from 0·03 in. to 0·08 in., the corresponding net figures being about 990 and 1,560 kWh.

With gas carburising in a small electric furnace a case of 0·03 in. requires less than 475 kWh per net ton, a saving of over 50 per cent.

(2) *Brass Annealing.*—Batch electric furnaces operate with a consumption of 100 to 120 kWh per ton, compared with a theoretical figure of 83 kWh per ton.

Recuperative electric furnaces, used during the war to anneal brass cartridge cases, gave a figure as low as 45 kWh per ton.

(3) *Malleableising.*—The old method with coal-fired furnaces required from 1 to 1½ tons of coal per ton of castings, and with large continuous gas-fired furnaces some 16,000 cu. ft. per ton.

With the new gaseous method in a batch electric furnace the consumption is about 700 kWh per ton, equivalent to 7 or 8 cwt. of coal at the power station.

(4) *Induction Heating for Forging.*—In the heating of bolt blanks, 1-in. diameter, 2⅞-in. heated length, the consumption at the supply mains is 120 kWh per 1,000 blanks, or 416 kWh per ton of steel heated. This is an efficiency of 57·5 per cent., or 16 per cent. on the fuel at the power station.

The present fuel-fired furnaces have an efficiency of less than 8 per cent. and produce appalling working conditions.

(5) *Induction Surface Hardening.*—With this the consumption is usually about one-third of alternative electric methods, giving a better produce with a great saving in time and labour.

FUTURE TRENDS

Continuous furnaces which give a higher efficiency and a steadier load will be increasingly used, especially in mass-production plants.

New processes in which the period of treatment and the dead-weight (containers, carriers, etc.) is much reduced, will gradually displace the older and less efficient ones. Examples of this are in gas carburising and gaseous malleableising, in both of which the use of heavy containers and packing, which have to be heated with the charge, are eliminated.

High-frequency induction heating, cutting out the necessity of heating more than the actual portion requiring treatment or indeed anything but the actual work, is another direction where considerable economies will be effected.

These induction methods, it should be said, are not being introduced primarily to save fuel, but because of the very considerable savings in labour, space, etc., which make the total costs much lower than with the older processes, electric or otherwise.

In general, since every advance in metallurgical science calls for more specialised heat control, electric heat treatment and melting will be increasingly used. In spite of all improved efficiencies likely to be obtained there is bound to be an ever-growing demand for electric power for this purpose.

Discussion

Mr. Evans maintained that good mechanical engineering was necessary in furnace work, and that good operatives were equally essential. Use might be made of the heat liberated during the cooling of the stock.

Prof. Aitchison held that the mechanisation of furnaces was even more important than instrumentation. He endorsed Mr. Armstrong's view of the desirability for close co-operation between designers and users.

Mr. Wardrobe said that every attempt was made by the steel industry to collaborate with designers and to take full share of the responsibility. Industry in effect designed its own furnaces and believed them to be efficient. He asked for further information on hot-face refractories to work at 1300° C.

Mr. L. R. Barrett replied that hot-face refractory insulating bricks were available for use up to 1300° C. These were preferably made from high-alumina clays, sillimanite or other highly aluminous materials. Names of makers could be obtained from the British Refractories Research Association.

Mr. Wardrobe went on to ask whether there was available a reliable raw-gas meter suitable for use with producers on melting furnaces ? While instrumentation was good up to a point, with too many instruments there was a danger of getting out of balance. He agreed that fully-loaded furnaces were the ideal, but pointed out that the orders available did not always permit of 100 per cent. load factor.

Dr. Leckie said that it was now possible to meter raw gas except in one or two special circumstances.

Mr. Austin considered that it was essental that there should be co-operation between the works, the instrument maker and the furnace designer.

Mr. Stewart pointed out that even with instrumentation and automatic control, skilled labour was needed to look after the instruments. The care of instruments should be taught in technical colleges.

Mr. Glynne Lobley, in reply to a query, said that all electric furnaces should be thermostatically controlled. No pyrometer would stand up to 1250° C. and it was very necessary that one should be made available. Standby losses from electric furnaces were relatively unimportant.

Mr. West-Oram also spoke.

Mr. R. F. Hayman wrote : What is the difference, in Mr. Southern's paper, between his quantity w_{ga} (wt. of products of combustion per unit of fuel at θ_F) and his w_{ge} (wt. of products of combustion per unit of fuel at θ_E) ? I should have thought that the weight of products per unit of fuel was the same at any temperature.

Mr. Glynne Lobley's statement that standby losses from electric furnaces are relatively unimportant is surprising ; I have always believed that any losses were progressively more serious with increasingly higher grade of fuel. Is it inferred that all electrical equipment is thermostatically controlled and therefore that losses are cut down to the minimum ?

Mr. Southern wrote that the weight w_{ga} referred to the weight of the products of combustion per unit of fuel at the point of maximum temperature θ_F, whereas w_{ge} referred to the weight at the outlet port. The difference between these quantities was due to air infiltration. This was illustrated in the applications of the equations to the development of a blast-furnace gas fired continuous recuperative furnace (immediately following Equation 15) where 6 per cent. of excess air is assumed at the fore-hearth and 20 per cent. excess air at the outlet ports.

Mr. Glynne Lobley wrote explaining that his meaning was not that standby losses with electric furnaces were unimportant, but that they were not so serious as with other types. This was due to good insulation and to absence of flues. The standby loss was usually of the order of 10 per cent. of the full rating. With short shut-downs the energy required to re-heat the furnace would be practically as much as that required to cover standby losses with a furnace kept at full temperature, and would often entail a load at peak periods. Practically all electric furnaces were thermostatically controlled.

Mr. L. B. Lambert referring to the statements made that thermocouples could not be used in forge furnaces at 1250° C., wrote : Thermocouples can not only be used at this temperature satisfactorily, but many are in use in gas-fired furnaces up to 1350° C., at which temperature a life of six months can be expected before maintenance is required. The use of thermocouples in forge furnaces is not considerable. This is partly due to the difficulty of avoiding flame temperatures and to the slagging effect of oxide particles. Furthermore, forge masters like to have a " wash heat " as they consider that this enables a greater output to be obtained. Sometimes the outside of the billet is up to " wash heat " but the rate of temperature rise has been too fast to ensure that the billet is at uniform temperature throughout. There is little doubt that the desirable procedure is to control forge furnaces at a temperature which gives a balance between maximum production and fuel economy. With the present high cost and shortage of fuel, the extra cost of equipping furnaces with temperature measurement, or preferably control apparatus, and the small amount of extra maintenance required, will be amply repaid.

Mr. James Law wrote : Attention should be paid to furnace practice. Furnace operators have been and still are paid on results, or as it is termed on " Tonnage ". The tons of " fabricated material " completed are the essential factors, not the " *tons produced per ton of fuel used* ". The result is that fuel is sacrificed for the sake of maximum output and the unfortunate part of the system is that in many cases the furnace operator can ignore fuel efficiency and dictate to the management how furnaces shall be operated. Mr. Armstrong wished for controlled furnaces that could be operated as simply as machines, but even furnaces of such simplicity will be of little use, until a change of policy takes place, and " tons produced per quantity of fuel used " becomes the rightful manner of paying bonus to furnacemen. Furnace practice as carried out at present in many of the Sheffield works requires drastic adjustment if fuel economy is to be achieved.

Mr. M. W. Thring wrote that there were three distinct levels of research needed for the improvement of furnace design. These were (*a*) pure, or fundamental research, (*b*) industrial research which directly benefited mankind, and (*c*) intermediate research linking the two. All three were essential. Fundamental research had not been mentioned at this meeting but it involved such things as the use of aerodynamic models for the study of the laws of gas flow in gas systems to provide a background similar to that which air tunnels provide for aircraft, the fundamental study for physical processes taking place in combustion, the investigation of the laws and theory of heat transfer, and the development of instruments for probing inside furnace systems. As part of the industrial research work, the writer mentioned the work of teams of scientists equipped with special probes and recording instruments for finding out in detail what is going on inside a furnace, work which is already being pursued actively by the Steelmaking Division of The British Iron and Steel Research Association and by the Combustion Research Department of the British Coal Utilisation Research Association, using the heat-flow meter.

SECTION D.
HIGH TEMPERATURE PROCESSES—*continued*

SESSION IIIa. The Modern Gas Producer

Chairman of Session: MR. G. N. CRITCHLEY
MEMBER OF THE FUEL EFFICIENCY COMMITTEE,
LATELY DIRECTOR OF THERMAL ENGINEERING, MINISTRY OF SUPPLY

THE CHAIRMAN : A recent estimate indicated that approximately 6·5 million tons of coal are gasified each year in producers in this country, about 5·2 million tons being used in the iron and steel industry, 700,000 tons in the glass industry and the remaining 600,000 tons in other industries. Thus about 80 per cent. of all the producer coal gasified is used in the iron and steel industry. Between 50 and 60 per cent. of all the coal used in manufacturing iron and steel is, in fact, first converted into producer gas.

Being gaseous, producer gas can be both readily controlled and readily preheated, and this, combined with its cheapness compared with other fluid fuels, accounts for its extensive use in a number of major industrial processes. Even at the present time, with coal costs greatly increased compared with pre-war levels, raw producer gas can be generated from coal at a total cost, including interest and depreciation, of approximately 3*d.* per therm, and at this cost there is a strong economic case favouring its use for such processes as steel melting and glass melting.

Whether or not producer gas will play as great a part in the future of British industry as it has in the past will be affected by economic considerations, by the availability of raw fuel and by technical progress yet to be made.

Economically it is, as I have already said, well able to compete with other fuels for a number of important industrial processes, and if coal of the quality gasified in producers before the war were to be available to meet future demands there is, I think, little likelihood that other fuels would, unless entirely new processes are developed, oust producer gas from these fields.

If, however, supplies of what we have hitherto known as producer coal continue to be reduced, then we will be faced with the need neither for substituting some alternative fuel for producer gas or for developing plants capable of generating producer gas from raw fuels other than producer coal of the quality hitherto used.

If, as may be the case in future, coal of the quality hitherto used in producers is to become more and more scarce, it becomes of great importance, firstly that raw fuel shall be gasified as efficiently as possible in existing producers, secondly that the producer gas generated shall be used as efficiently as possible in the furnaces it fires, thirdly that research and development work should be concentrated on means whereby producer gas can be both generated and utilised more efficiently than is possible in plants of existing designs, and fourthly that corresponding work should be devoted to the development of plants capable of utilising the grades of raw fuel which will be available in the years to come.

There have been, one regrets to have to say, no developments in producer design in recent years which have resulted in any marked improvements in thermal efficiency. Replacement of the older static-hearth types by rotary-hearth plants has been taking place steadily. This change, combined with improved instrumentation and operation, has unquestionably raised the average efficiency of generation, but no recent improvement in design as such has made a material contribution to the much needed economy in producer fuel.

A really substantial improvement could, in fact, result only from a radical change in design as compared with existing plants, and in searching for directions in which such major improvements might be found, three possibilities would appear to be worthy of special consideration.

The first of these possible means of raising efficiency, and to my mind one which holds out a prospect of far reaching results, would be effected by preheating the blast to a high temperature, whereby much of the heat required to maintain the fuel bed at reaction temperature would be supplied to the generator as sensible heat in the blast. A blast temperature of about 900° C. might ultimately be attained, and a temperature of this order would allow a much higher proportion of steam to be introduced in the blast than is possible with existing processes. In addition to being generated at greater efficiency, the resulting gas would have a substantially higher calorific value than ordinary producer gas and could, in consequence, be utilised more efficiently in the furnace.

It is usually unfair to forecast what a process will do before it has been tried. In the present instance we are fortunate in that much fundamental work has already been carried out and published, and I think it safe to anticipate that, if a suitable plant could be developed from this basic work, the calorific value of the fuel might ultimately be of the order of 200 B.Th.U. per cu. ft. as compared with the present average of about 140 B.Th.U. per cu. ft., and that the new producer would need about 10 per cent. less raw fuel, for a given output of gaseous fuel, than is required by existing plants.

These provisional estimates are intentionally qualified by the proviso that, before they could be realised, a great deal of development work would have to be based on the fundamental work already at our disposal.

The second of the three possible means of raising efficiency arises from replacing the air in the blast by oxygen. Theoretically this would have the advantage that the resulting producer gas would be free from nitrogen, and would, therefore, have a substantially higher calorific value than could be obtained with an air blast. Oxygen has already been used on a large scale in Germany for generating synthesis gas from brown coal in Winkler producers. It could become an economically practicable method of manufacturing gaseous fuel only if oxygen were substantially cheaper than it is at the present time.

The third possible means of raising efficiency lies in the development of automatic controls which will make producer gas plants increasingly independent of the wastage which results from poor operation. Control of the coal feed, of the blast saturation and of the ash discharge are numbered among the factors exercising a major effect on efficiency.

So much for the thermal efficiency. There remains the almost certain need for using fuels of lower grade than those hitherto available.

In facing this problem the fundamental research work recently carried out on size segregation, and on the possibility of controlling distribution of the raw fuel in such a way that this segregation does not result in uneven gasification, merits close consideration for development. And if, to visualise the extreme case, there is a probability of our having, in future, to use coal containing a high proportion of fines, we may even have to consider the possibility of generating producer gas, not from lump coal, but from jets of fine coal injected into a generating chamber, just as pulverised fuel is fed into a furnace.

1. The Gasification of South Wales Coals

By DONALD HICKS, M.SC., F.R.I.C., A.M.I.CHEM.E.

There are many good reasons why producers should be operated efficiently. Two of the most important are :—(1) If the management are of a mind to ensure that producer operation is efficient then there is a reasonable chance that other aspects of works management will be subject to close operational control, so establishing conditions which will ensure a good overall fuel economy. (2) The second reason, which is really a corollary of the first, is that if a consistently high quality producer gas is delivered at the furnace valve at a constant pressure the producer variable is eliminated and attention can be devoted to supervising other aspects of furnace practice such as the efficiency of combustion of the gas, the flow of materials, the metallurgical control and the schedule of maintenance of the furnace structure and flue system. These factors are frequently of great importance in determining the fuel economy of a process.

Two classes of South Wales coals are normally used in producers, namely, the anthracites (volatile matter content 5–9·5 per cent.) and the bituminous 3 coals (volatile matter content 29–35 per cent.).

The anthracites are generally used when a cold clean gas is required for use in heat-treatment furnaces, and the bituminous coals when a hot raw gas is required for high-temperature melting and reheating furnaces.

The efficient gasification of anthracite is not difficult in the modern producer and it is worth recording that the visiting engineers of the South Wales Fuel Efficiency Committee who have surveyed every producer plant in the region have on no occasion had to record inefficient producer practice when anthracite has been the fuel.

The choice of the type of anthracite is not important except for suction gas plants when the higher rank anthracites are necessary because of the low yield of tar. It is always advisable when purchasing anthracite for producers to state the type of plant in which it is to be used and then the suppliers can select and deliver the correct class and grade. The marketed anthracite grades are washed and closely sized and a fuel of constant quality both in respect of ash content and screen analysis can be delivered.

Generally the manufacturers of producer plant designed to use anthracite supply a reliable and well-instrumented machine which the average intelligent workman can quickly be trained to operate efficiently. Orderly log sheets are provided and the operators record at regular intervals the condition of the fire and ash beds, air and gas pressures and the times of charging and grating, the gas offtake temperature and the blast saturation temperature. Usually it is desirable to experiment to find the most economical blast saturation temperature, balancing quality of gas against the ease of control of clinker formation. Rarely should it be necessary to use a blast saturation temperature greater than 60° C. and with most anthracites, provided the rate of gasification is not too high, the most economical blast saturation temperature will be found to be within the range 55°–58° C.

It is important always to determine the most economic rate of gasification for the particular plant and grade of fuel. The smaller the size of the anthracite the lower the effective rate of gasification. With most of the producers now in operation the most efficient gasification rate when using small nuts or beans is of the order of 20 to 25 lb. per sq. ft. of hearth area per hour. When peas are used the rate is reduced by approximately 20 per cent. and if grains are used the reduction is often as much as 40 per cent. with an increased pressure drop across the bed frequently demanding a greater fan capacity. Attempts to operate at faster rates than the above result in high fuel bed and gas offtake temperatures, hot spots with rapid clinker formation and a poor gas. If a producer is being operated to its maximum capacity with small nuts or beans then it will not be possible to meet the demand for gas by using the smaller sizes such as grains. On the other hand, if there is ample producer capacity a switch from a larger to a smaller size can be made without any disadvantage provided the air capacity is sufficient.

Although as stated above most of the anthracite-using producers rarely exceed an efficient gasification rate of 25 lb./sq. ft./hour, there is one type of producer in operation in this country which regularly gasifies anthracite at the rate of 50 to 55 lb./sq. ft./hour (see " Gasification of Low Volatile Fuels ", by H. R. Forman, J. Inst. Fuel, XVII, 109). It is impossible to say precisely what features in the design determine this high rate of gasification but designers generally are now concentrating on grate and blast tuyere design to improve the gasification rates and already the older designs which were incapable of rates greater than 25 lb./sq. ft./hour have been modified to give rates of up to 35 lb./sq. ft./hour with certain selected grades. However, the final issue is that the producer gas delivered at the furnace shall be of such a quality that it can do the work required of it and that the cost per therm shall be such that it will compete with other suitable fuels.

To get a true picture of the South Wales bituminous producer fuels it is desirable to compare them with the recognised producer fuels marketed from the English and Scottish coalfields (see Table IV—Fuel Efficiency Bulletin No. 44—" The Operation of Gas Producers ").

In contrast to the pedigree producer fuels of the Notts and Derby and Scottish coalfields which are feebly to medium caking and closely sized, most of the South Wales bituminous coal supplied for use in producers is strongly caking and usually unsized. The South Wales bituminous coals have agglutinating values of 30 and greater, swelling indices of 7 and greater and give Gray-King assay coke types of G_8 and over. The raw coal mined at many of the bituminous gas coal collieries contains such a high percentage of fines that the screening out of nuts and beans to meet this special market would be uneconomic. Consequently a large percentage of the coal used in the producers at the local steelworks is a through coal of a size approximately 4 in.–0 containing as much as 40 per cent. through a ⅛-in. mesh screen. Furthermore, most of this coal is unwashed and ash contents averaging 13 to 15 per cent. are not uncommon.

The effect of the strong caking properties and the high percentage of fines is to aggravate the normal difficulties of producer operation and to reduce considerably the efficient rate of gasification. The feebly-caking sized English coals can be gasified in mechanical producers at rates up to 50 to 55 lb./sq. ft./hour. The sized strongly-caking South Wales bituminous coals cannot be gasified in the same producers at a rate of more than 35 lb./sq. ft./hour and the South Wales unsized " through " coals have an efficient gasification rate of about 20 to 25 lb./sq. ft./hour. When this is appreciated and the correct number of producers installed to meet the load it is possible with careful control to get excellent results from the South Wales coals. To balance the disadvantages compared with the English coals it must be remembered that the calorific value of the South Wales coals is approximately 15 per cent. and sometimes 20 per cent. higher than the English and Scottish producer coals which are imported into the area. A recent survey of coal supplied to one of the South Wales steel works from many different sources showed that the South Wales coals were equivalent to approximately 300 therms per ton and the English producer coals were approximately 260 therms per ton.

The strong caking properties and high percentages of fines often result in high gas-offtake temperatures, channelling in the fuel bed with resulting hot spots and heavy clinker formation. Careful attention to the rate of feed, to consolidation of the fuel bed and maintaining a uniform ash bed largely overcome these difficulties. The control of the rate of feed is most important with these coals and the introduction of the automatic control of the gas offtake temperature is strongly recommended as a step to the establishing of good bed conditions. In those producers where the shell of the producer and the fuel bed revolve it is most important to ensure the correct speed of rotation. A frequent mistake is to have too slow a rate of revolution which often results in a higher rate of gasification at the periphery than at the centre. This can often be overcome by speeding up the machine. The automatic control of the gas-offtake pressure also assists in keeping steady conditions and eliminates erratic working which is fatal with South Wales coals.

The high percentage of fines results in a big carry-over of dust, necessitating frequent emptying of dust catchers, and a rapid build-up of dust in the gas mains. This is an added charge to the total costs but a regular routine of burning out and cleaning mains ensures smooth working and obviates the necessity for high gas-offtake pressures.

One colliery company marketing a washed gas " through " has improved the quality by a partial removal of the fines during washing and the coal gives excellent results at a gasification rate of about 25 lb./sq. ft./hour. Another company marketing a wrought " through " upgrades the size by removing some of the ⅛-in. to material and briquetting it, returning the ovoids to the " through " before despatch. This is only a partial solution, but recent large-scale trials, using 100 per cent. small ovoids made from this coal have given excellent results in the mechanical producer supplying gas to an open-hearth furnace and probably the solution to the upgrading of the South Wales bituminous gas coals is via washing and briquetting provided the overall cost of conversion is not too high.

The efficient gasification of South Wales coals can be guaranteed provided there is close supervision of the producer operation throughout the 24 hours. This will entail a frequent determination of the CO_2 content of the gas, a close watch on the blast-saturation and gas-offtake temperatures, careful control of the rate of feed and the state of the fuel bed, the intelligent removal of the ashes, determined by the rate of build-up rather than by a time schedule, and, what is equally important, a regular routine of overhaul and maintenance.

The operatives cannot be expected to get good results without the aid of accurate and well sited instruments and the first aim should be to make the operation as fully automatic as possible.

There is no guarantee that if the producer gas quality is good and the efficiency of operation high, the overall fuel economy of the process will be satisfactory. The poor fuel economy at many works has too frequently been attributed to poor gas due to what was stated to be poor coal when the real reason was shortcomings in other phases of the process operation.

2. Gas Producers in the Iron and Steel Industry

By F. A. GRAY

APPLICATION OF PRINCIPLES

The Ministry is to be congratulated on bulletin No. 44 " The Operation of Gas Producers ", which is an excellent practical guide. The main problem which still remains is that of getting these principles applied to works practice.

A producer superintendent should always be appointed, and he must be given the support that will enable him to run the plant efficiently.

If producers are to be worked efficiently, we must have men trained in producer operation ; men who can quickly recognise when something is wrong and can put it right. There should be a gas producer training centre or centres where firstly supervisors and later operators can be sent for a course of practical training supplemented by lectures based on Fuel Efficiency Bulletin 44.

In addition to trained supervisors and operatives, it is necessary that the plant should be kept clean and tidy, be properly maintained, and well lighted. The condition of the plant should be such as will induce the operators to take a pride in their work.

PRODUCER OPERATION

The bulletin (page 31) suggests that in certain conditions the producer blast may be operated by the furnaceman. Dual control is, however, unsatisfactory and should be avoided.

Coal of the correct types and sizes should be allocated for producers. A low sulphur coal is essential for making steel by the acid process where it is not possible to remove sulphur from the metal. Whilst it is possible to remove sulphur in the basic process within certain limits, the lower the sulphur in the fuel, the better it is both from the steel making and the fuel economy points of view. High sulphur fuels mean increased slag bulk, with reduced rates of heat transmission and steel production and consequently greater heat consumption per ton of product.

Whilst it is true (bulletin, p. 12) that a wet measuring rod indicates a leaking leveller, it is possible to have a leaking leveller and not show a wet rod. Water leaking into a producer shows itself in a reduced rate of gasification, a cold fuel bed, tar deposition in the mains and a high CO_2 content of the gas. The only sure method, however, of ascertaining whether a suspected leveller is really leaking is to take it out for examination.

A point which is not mentioned directly in the bulletin is the desirability of running the producer at a minimum pressure demanded by the system to be supplied. High blast pressures favour channelling and inferior gas. With high back pressures, and where steam-jet blowers are used, it may be impossible to reduce the saturation temperature to the required figure, with resultant loss in producer efficiency. In this connection, a multiple blower composed of a number of small jet blowers, is usually capable of inducing more air per unit of steam than a single jet blower of similar steam capacity. Where a single jet blower is used, the saturation temperature can often be reduced by using a slightly smaller jet and raising the steam pressure behind it. Alternatively, a turbo-blower may be used where high blast pressures are required.

Instrumentation and automatic control are very important. Automatic gas-pressure control is widely practised but there should be more automatic control of coal feeds, the control gear being actuated by the quantity of air or steam delivered to the producer, with automatic saturation temperature control as a necessary ancillary.

When raw gas is transmitted, there should be adequate dust catchers at the producer offtake and provision of cleaning doors at points on the gas main where changes of direction occur. Accumulations of dust can materially affect producer efficiency by causing excessive back pressures. Soot-blowers built into the bottom of gas mains are satisfactory and effective for removing dust deposits during burning-out periods when properly operated to avoid excessive temperatures. It is important to arrange the blowers so that they blow in the direction of the burning-out stack.

The insulation of raw gas mains is necessary for two reasons, namely to reduce the loss of sensible heat in the gas and equally, if not more important, to prevent the loss and deposition of tar. The presence of tar in the gas is important in giving increased radiating power to the producer gas flame ; this is particularly so in the case of high temperature furnaces. The use of hot-face insulating bricks should be considered as also reducing the weight of the gas main. The use of hot-face insulating bricks raises the question of tar penetration. It may be of interest to give the results of laboratory tests on tar penetration conducted by the United Steel Companies Research and Development Department :—" Tar penetration into high temperature insulation bricks can be minimised by the application of a thin wash of a suitable cement which matures at a relatively low temperature, e.g. finely ground fire clay and cement-fondu made up with water-glass solution. Such coatings reduce tar penetration to the same order as that obtained with fireclay brick. They are stable up to 800° C. and show no tendency to flake off due to thermal shock."

SUBJECTS FOR RESEARCH

(i) The raising of cold gas efficiency (when the gas is to be used cold) by using the sensible heat in the gas for preheating the blast, and thus returning it to the producer. The sensible heat in producer gas at the producer, is of the order of 10 B.Th.U./ft.^{3} and 20 B.Th.U./ft.^{3} with coke and coal-fired producers respectively. These amounts represent say 7 and 12 per cent. of the heat input to the producer. When coal is the producer fuel, it would seem that it would be necessary to take off the gas at two points, as done with the Schwel gas producer, and to use a heat exchanger at the lower gas outlet, namely for the hot, comparatively tar-free gas coming from the coke section.

(ii) The use of oxygen-enriched blast.

(iii) Purification of hot raw gas from sulphur, i.e. without cooling. Success here would increase steel production and reduce fuel consumption.

3. The Gas Producer and the Chemical Industry

By DR. A. C. DUNNINGHAM and R. SCOTT

SUMMARY

The purpose of this contribution is to show that gas producer firing may be uneconomic as compared with mechanical stokers burning solid fuel and that in many chemical processes it might with advantage be replaced by the latter. If the use of producer gas is essential, careful consideration should be given to the method of production in order to reduce the cost per therm to the lowest possible figure and where clean cold gas is essential the recovery of sensible heat from the hot gas should also receive careful consideration.

RELATIVE COSTS

A therm in the form of producer gas is more costly than a therm in the original solid fuel from which it is produced because,

(*a*) some of the heat is lost during the process of conversion,

(*b*) labour and operating costs are incurred in the process of gasification.

(*a*) *Thermal losses.*—As regards thermal losses the net hot-gas efficiency of a producer fired with bituminous coal based upon the gross calorific value of the coal, together with the total heat of the steam supplied to the blast rarely exceeds 85 per cent., whilst 65 per cent. is a good figure for the cold gas, making no allowance for the recovered tar which seldom has any very considerable value. The cold gas efficiency of a producer fired with coke or anthracite is higher because no tar is formed and in such cases it may be possible to recover much of the sensible heat in the hot gas in the form of preheat of the blast. In such circumstances the cold gas efficiency may approximate to 80 per cent., that is, it may be almost as high as the hot gas efficiency.

(*b*) *Costs.*—A careful analysis has been made of the costs at a number of producer plants and as a result it has been possible to determine the approximate average cost of a therm in producer gas as compared with that of a therm in bituminous coal, the fuel which would almost invariably be used on a stoker-fired plant. Taking the cost of a therm in the coal as 1·00 the following figures give the cost of a therm in producer gas prepared in various ways.

	Relative cost of therm
Bituminous coal	1·00
Hot gas from bituminous coal	1·55
Cold gas from bituminous coal	2·10
Hot gas from coke	2·00
Cold gas from coke	2·35
Hot gas from anthracite	2·42
Cold gas from anthracite	2·59

In making this comparison the cost of bituminous coal has been taken at 40*s.* per ton, that of coke at 60*s.* and anthracite at 72*s.* per ton. The cost of heat supplied in the form of producer gas without recovery of sensible heat in the case of cold gas is then equivalent to the following prices for bituminous coal :—

Bituminous coal	40*s*. per ton
Hot gas from bituminous coal	62*s*. „
Cold gas from bituminous coal	84*s*. „
Hot gas from coke	80*s*. „
Cold gas from coke	94*s*. „
Hot gas from anthracite	96·8*s*. „
Cold gas from anthracite	103·6*s*. „

It will be seen that in an extreme case using cold gas prepared from anthracite the cost of heat in the gas may be equivalent to using coal at over £5 per ton.

It has commonly been supposed that producer gas can be burnt and the heat utilised more efficiently than is the case with coal. This, no doubt, is true when the coal is hand fired, but trials recently made on a sulphuric acid concentration pot have shown that equal efficiencies can be obtained with either producer gas or an underfeed stoker and that output and quality of product can be well maintained. The capital cost of the producer plant and of the stokers necessary for solid-fuel firing, more or less cancel out, whilst furnace operating costs are not widely different. The above comparative figures therefore correspond approximately to the cost of *effective* heat units as utilised in the furnace.

Estimates of the amount of coal used for the manufacture of producer gas in this country vary from 6–10 million tons per annum. If, therefore, the losses arising from the conversion of coal into producer gas were eliminated by the substitution of stoker firing, savings of the order of 1–2 million tons per annum could be envisaged, whilst the actual monetary cost of heat supplied to furnace and other plant would probably be halved. It is not suggested, however, that all producer firing could be replaced by mechanical stokers, although this might very well be done in many cases.

REASONS FOR THE USE OF PRODUCER GAS

Producer gas firing is usually used on account of (*a*) its convenience, (*b*) the uniform temperature and ease of control of combustion obtainable by its use, or (*c*) its freedom from dust and sulphur gases likely to contaminate material coming into contact with the products of combustion.

(*a*) *Convenience.*—The distribution of producer gas from a central generating plant has obvious advantages as regards convenience of operation and eliminates the costly handling of coal and ashes in small quantities at a number of points. It may also avoid the installation and operation of a large number of small mechanical stokers and in some cases this may be of considerable economic advantage which must be balanced against the increased cost of heat in the form of producer gas.

(*b*) *Ease and Uniformity of Control.*—With regard to ease of control of combustion and uniformity of temperature, it has already been mentioned that tests at a sulphuric acid concentration plant have shown that coal mechanically fired on an underfeed stoker can give equally good results and this may prove to be the case in a great many other processes. The avoidance of local heating is of considerable importance not only in connection with the product itself, but in order to prevent local damage to the plant. This can only be tested over a long period, but up to date there is no indication that any such damage is occurring. This may be due to the fact that the stoker installed at the test plant is larger than necessary and that at a comparatively low burning rate a long, well distributed flame is produced in place of the short intense flame which might occur at a higher burning rate.

(*c*) *Cleanliness.*—As regards the cleanliness of the gas, this may be an over-riding factor where the products of combustion come into direct contact with the material being heated, although it may in some cases be possible to adopt a somewhat lower standard of purity than that hitherto insisted upon. Apart from this, however, it is sometimes possible to modify the plant in such a way as to avoid direct contact between the product and the combustion gases and so to avoid contamination. An instance of this occurs in salt cake manufacture. In the case of the reverberatory type of furnace, the products of combustion carry away the hydrochloric acid gas which is separated from them by solution in water. Discolouration of the product, however, occurs with coal firing and the use of producer gas becomes necessary. A muffle type of furnace, however, can be used in which the combustion gases do not make contact with the reacting mass and a clear acid product can then be obtained even with coal firing. It may be noted that in order to remove tar and dust, producer gas must be cooled and this involves a considerably lower efficiency than with hot gas. This, however, can be largely remedied by the use of coke or anthracite, together with the recovery of sensible heat in recuperators, which may be constructed of heat-resisting metal. Although this is very costly at present, the higher output made possible by increased demand would undoubtedly bring prices down to a more economic level.

CONCLUSION

This very brief statement shows that considerable savings of both coal and money may often be obtained by the substitution of a stoker for producer gas firing. In view, therefore, of the increased cost of fuel and of the critical position as regards fuel supplies, the use of producer gas, in both existing and new processes should receive the most careful consideration with a view to its possible elimination. If process requirements will not allow this, every effort should be made to increase the efficiency of the gasification and cleaning processes along the lines indicated above.

4. The Gas Producer in the Glass Industry

By DR. E. SEDDON

(1) RELATION BETWEEN FURNACE EFFICIENCY AND PRODUCER DESIGN AND OPERATION

Amongst the factors influencing furnace efficiency, we must regard optimum heat transfer from flame to batch or molten glass as one of the most important.

Whilst certain methods of feeding glass batch may assist materially in this heat transfer, the flame characteristics are probably even more important.

Our aim is to combine high luminosity with optimum flame temperature. We consider that, other things being equal, the raising of the calorific value of the producer gas is an aid to furnace efficiency ; we are further convinced that the calorific value alone is not the sole criterion. Producer gases rich in tar, and containing a high proportion of hydrocarbons, seem likely to yield, and, in fact, are found to give the best results. A high ratio of CO/H_2 may be desirable ; excessive moisture content in the producer gas before burning, or even a high hydrogen content (which yields excessive moisture after burning) probably exert a considerable influence, perhaps deleterious, on heat transfer to the batch or to the molten glass.

The glass industry is thus vitally interested in producer design and operation, not only for its own sake, but for the distinct advantages it brings in improved furnace efficiencies, i.e. in quality of product, quantity of product and cost of product.

Amongst the factors we regard as influencing gas quality and composition, can be included coal quality (chemically and in size grading), coal distribution to ensure even gasification rates over the whole producer area, good bed conditions, correct poking and agitation, good blast distribution with the air/steam ratio correctly proportioned and without appreciable free moisture, an absence of channelling, correct ashing and a reasonably low gas-exit temperature to ensure a high calorific value gas with good luminosity due to contained tar or hydrocarbons, the former being prevented from deposition by short, well-insulated flues.

(2) QUALITY OF PRESENT-DAY PRODUCER COAL

Although we realise to the full that the present is scarcely the time to ask for producer coal to be supplied to a rigid pre-war specification, we do consider that glass manufacturers, in common with other industries, should even now be indicating the type of coal, regarded, in the light of practical experience, as most suitable for our industry, and should be asking when it may again be possible for us to obtain coal qualities similar to, if not identical with, those we obtained before 1939.

Our laboratory determinations of coal properties, and our observations of the coal in use on our producers, both suggest that present coal quality is " debased ". Chemical and thermal properties may not have declined so much as mechanical size grading. We consider that there has been in increase in the proportion of " fines ", and this has resulted in an increased quantity of ash ; the latter often has fusion properties different from the properties of coals formerly used. This may be due to the mixing of coals from different seams. The excessive amount of " fines " causes much more poking, because of clinker formation ; this clinker has properties quite different from those of pre-war coals. " Fines " are worst in coal which has been sea-borne, due, no doubt, to friability of the coal in loading, in transit and during unloading.

In our view, the poorer coal, and in particular the presence of " fines ", sets up a vicious spiral in producer operation, with a general lowering of furnace, as well as of producer, efficiency. Coal with a high proportion of " fines " causes the producer to run hot ; the calorific value of the gas and its luminosity diminish appreciably more than any gain due to higher flame temperature caused by the extra sensible heat of the gas. As the heat transfer to the glass falls off, a greater volume of gas is needed. The producer, already hot, then has to be forced still harder with a further bad effect on gas qualities. The vicious spiral, once started, continues apace, until drastic action is taken to stop it. Furthermore the " fines " are carried over into the flues, causing choking back pressure, waste of combustible material, and expense of removal.

More fuel might be saved if producer coal quality could be improved in the future. As and when the coal position improves, the glass industry hopes that attention can be paid to the statement of their requirements, submitted to the Ministry some little time ago.

(3) COAL DISTRIBUTION

Optimum conditions can never be attained in the producer, unless full advantage is taken of the whole of the producer area. It is not enough to speak of mean rates of gasification of so many lb. of coal per sq. ft. ; we need to ensure that each square foot of area is doing its fair share of work.

By studying closely the positioning and arrangement of distributors and deflectors at the start-up and during operation of the producer, it is possible to improve, quite considerably, the distribution of coal over the whole area of the bed.

Good coal distribution can help considerably in minimising flaring, which is invariably most pronounced at the centre and the extreme outer annulus of the bed ; these two areas together may equal one-fifth of the total producer area. By cutting out flaring and channelling, clinker formation can be minimised or even avoided entirely.

(4) METERING HOT RAW PRODUCER GAS OR MEASURING COAL QUANTITY

Like other industries using gas producers, we should like to meter the hot raw producer gas, measure its calorific value, and determine its composition, including moisture content, as a means of controlling furnace operation and studying optimum furnace efficiency. If this cannot yet be achieved in its entirety, we need to measure coal quantity for deriving values for furnace performance.

As a means of checking coal consumptions derived in the ordinary way by truck weights and stocks in hoppers, we have used revolution counters on our coal drums. This method gives useful results (although there is some tendency for the drums to tar up gradually), and it also provides a check from shift to shift.

Alternatively, for special tests, the time taken to use a given weight of fuel can be measured accurately.

(5) BLAST CONDITIONS

Our experiments and experience with wet steam confirm the desirability of minimising free water in the blast. Dry superheated steam gives much better bed conditions.

As a means of further reducing the amount of free moisture, and of increasing the sensible heat, we have made experiments preheating the air portion of the blast. A steam heater was used for the purpose of these preliminary tests, but we consider that sufficient preheat could be obtained economically from the waste heat leaving our furnaces, up the main chimney stack, or even up the stack after passing through the waste-heat boilers. We observed improvements in bed conditions within the producer, and in the composition of the gas obtained, when the preheat was applied. There was some difficulty in maintaining the correct steam / air ratio under these conditions, and in further tests we propose to preheat the air/steam mixture *after* correct proportioning.

We consider that by preheating the blast we increase the rates of ignition and reaction, favour the endothermic reaction $CO_2 \rightarrow CO$, and obtain an increased sensible heat as well as extra chemical energy.

The blast saturation indicator and controller needs careful positioning, preferably in the straight portion of the blast pipe, to avoid free water effects ; it should lie in the stream of mixed air and steam. The instrument should be so positioned that it can readily be calibrated from time to time.

We use turbo-blowers to obtain maximum use from our steam.

The glass industry is interested in the use of the oxygen-enriched blast with its potential advantages of increased producer efficiency and greatly enhanced calorific values (of the resultant gas). The latter could yield the further advantage of greater furnace efficiencies.

(6) ASHING

From bitter experience we favour ashing continuously at a rate carefully chosen, and then fixed by rigid locking of the adjustment. This has resulted in much steadier bed conditions than prevailed before.

(7) POKING

This is of extreme importance in eliminating channelling and in removing clinker. The poking required varies considerably with caking or non-caking coal, and with the properties of ash. Poker tests are most valuable if made regularly.

(8) PRESSURES

We aim at keeping the internal pressures in our producers as low as possible, by locating and eliminating blockages in flues as soon as they start to collect. We do not wait for pressures to rise high enough to give trouble in the producer operation.

5. The Gas Producer in the Non-Ferrous Industry

By PROF. LESLIE AITCHISON, M.SC., D.MET., F.R.I.C.

It is difficult to speak of the use of gas producers in the non-ferrous industries because today they are employed comparatively little. During recent years there has been a declining employment of this method of heating and I think the best service I can render in this session is to attempt to arrive at the reasons for this position.

There are certain circumstances which generally operate in the non-ferrous industry. The first is that the industry does not use processes demanding very high temperatures and therefore is not forced to the employment of special methods of heating utilising the most advanced devices and plant. The second is that in the non-ferrous industry the cost of the fuel used in the fabrication processes is relatively low in relation to other cost factors, and consequently the selection of a method of heating is governed to a very large extent by operational factors, convenience and general economics.

In the non-ferrous industries there are relatively few plants in which there exist groups of furnaces, each of considerable capacity and therefore consuming a large quantity of fuel. In other words, the plant conditions are not such as would produce a steady load and a consumption justifying a central gas-producing outfit. The only exceptions that might be quoted in the copper and brass industries are the installations involving a number of furnaces for melting brass, and the furnaces used in copper refineries. For brass melting in sizeable plants producer gas has been ousted completely in favour of electricity. This latter heating medium brings with it the advantages of speed of operation, cleanliness, and convenience. In addition to that, the fuel consumption is low and even on a cost basis is one of the most economical in the whole of the operations covered by the industry. In refineries, and places where reverberatory furnaces are used, producer gas has shown no consumption or cost saving in comparison with other forms of heating, and today it is generally found that pulverised coal gives much better consumptions than are obtained with producer units and, of course, requires no separate piece of plant.

Apart from these instances, furnaces in the brass and copper industries tend to be distributed around the factory for use in reheating and annealing and, therefore, are properly located near to the mechanical plant they serve. Each of these furnaces needs relatively little gas, and it has not been found that such distributed heating units lend themselves to feeding from a central producer with cold gas. Separate small producers, which would be the alternative, are not so convenient as other forms of heating. They are less economical than a central installation and require a much larger number of skilled operators. The proper operation of any producer requires skill if it is to be achieved successfully, and a multiplication of units means a multiplication of craftsmen. The industries, therefore, have found it much more convenient, and generally more economical, to utilise town gas, oil, or electricity. Producer gas offers no other compensating advantages such as superior accuracy, ease of control, cleanliness, or the like. In addition, each producer is a separate piece of plant which involves capital outlay ; it takes up factory space ; it requires steam generation ; it needs efficient maintenance ; it needs a suitable fuel ; and, above all, it requires skilled men for efficient working. Further, for many purposes the rate of heating with producer gas is lower than can be obtained with, say, oil firing. Apart from the general inconvenience of this, the lower rate of heating means that the heating furnaces may be larger and therefore absorb a greater amount of factory space, quite apart from the space for the producer and its fuel bins.

Where the consumption figures are available, and there are still one or two installations using producer gas, there is nothing to suggest that a gain would accrue from the adoption of this mode of heating.

In the light alloy industry there is an opportunity for producer-gas heating where melting on a large scale is carried out in the production of billets and slabs for wrought manufacture, the melting in this case being done in reverberatory furnaces. Here a central producer unit is quite suitable and presents the advantage that no ashes have to be dealt with on the furnace, whilst the generally greater life of the furnaces, due to fewer local failures of the refractories, has made the process attractive. In a large installation of melting pots, producer gas may also be employed, though it does not seem to be exceedingly attractive. If producer gas is used for melting in reverberatory furnaces, careful attention has to be paid to the atmosphere in view of the susceptibility of aluminium to atmospheres with a high steam content.

Comparative consumptions in the melting of light alloys in reverberatory furnaces show nothing in favour of producer gas. In one works where both ordinary reverberatory furnaces and producer gas fires are working on an adequate scale, the fuel consumption in the reverberatories was 0·30 and 0·33 tons of coal per ton of metal melted, whilst the producer gas consumption, not including the steam-raising fuel, was 0·32 tons per ton.

Apart from the melting shop, the light alloy industries do not particularly lend themselves to producer gas heating. The accuracy of control and the cleanliness of electric furnaces are very appealing, whilst for reheating processes where accuracy is not of such supreme importance the rapidity with which metals can be heated with oil firing, and the smaller size of the furnace units makes the latter method very attractive. It would appear, therefore, that if producers are to be employed in the non-ferrous and light alloy industries, a special examination of the needs of both these industries is called for, taking into account the conditions operating in those industries which I have set out in much greater detail in the paper I presented to Session 1.* For the successful utilisation of producer gas I think a special design not only of furnaces but of whole installations is called for, and one of the most important points that needs attention in that connection is that of simplicity of operation coupled with the greatest practicable degree of mechanisation to reduce the extent to which proper working is dependent on individual craftsmen.

6. Latest Developments in Gas Producers and Directions of Progress for the Future

By A. FISHER

There are many problems calling for investigation in the manufacture and use of producer gas. British practice, in marked contrast to that of other countries, has been based on (i) simplicity of operation and (ii) the ready availability of suitable fuel. By contrast, in Germany, where developments have been centred on the use of brown coal and lignites, gasification under pressure, the use of oxygen, and the slagging producer ; these features have become highly perfected. Necessity, due to war conditions, when they were cut off from the ordinary sources of coal imports, led to some notable developments in Sweden, where, solely to meet the emergency, such fuels as straw, peat, waste wood, etc., were used to satisfy their gas producer requirements. The common problems with which British producer operators are confronted are due primarily to irregularity in both the quality and size (particularly in the direction of excess fines) in the fuel which they receive. Thus it has become important that gas producers should, by being able to deal with a wider range of fuels of inferior quality, meet the difficulties created by the general fuel shortage.

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* Fuel Considerations in the Fabrication of Non-Ferrous Metals and Light Alloys—British Non-Ferrous Metals Federation.

One feature in which all appear to be unanimous is that considerable advantage would accrue if the calorific value of the gas could be increased. German developments have pointed out ways of achieving this by gasification under pressure, and by the use of oxygen. This immediately raises the economic problem of the cost of oxygen, which is directly related to the cost of power for oxygen production. The estimated maximum power cost allowable for this to be economical, of about 1/10th of a penny per kWh in this country, is not at present attainable. The development of gas turbines may put us within reach of producing power at this necessary economic figure, as indicated by reports of developments in Russia, where it is understood large installations for the production of oxygen for use in the steel industry are under way, and the reports on progress in America in the use of pulverised coal for this purpose. On existing British equipment, the utilisation of waste heat for preheating the blast and superheating steam calls for investigation. Looking on conditions as they exist in this country today it would seem that specific research is called for in the following directions :—

(1) *The Fuel Bed.*—Recognising the mechanical efforts being made to maintain the ideal fuel bed conditions, the fines problem is the most important one to deal with. This calls for fundamental investigation of such problems as distribution of the flow of gas through the bed, the packing of particles, the method of release from the coals of volatile matter where bituminous coal is used, the sintering of fine particles where coking coal is used, the optimum blast saturation, and the study of the reaction mechanism of combustion. Another procedure for consideration is the desirability of screening out the fines for briquetting, experience on the use of which is available and would appear to call for wider application particularly in view of the better quality of gas attainable and reduction of dust trouble in mains. Obviously the more the operation is stable, automatic and closely controlled, the better ; to attain which, wider application of improved instruments is a necessity.

(2) *Gas Cleaning.*— Recent researches on open-hearth furnaces have shed new light on the part played by the tar in the producer gas flame. The production of the maximum tar in the gas by prevention of its destruction in the fuel bed or in dust removal is a desirable objective. Soot formation by its excessive inactivity in either the bed or the flame is to be avoided. The production of cold clean gas raises economic questions, one due to capital cost and the other the value of the tar recovered. It is recognised that modern plant installations with tar recovery have disproportionate expenditure for the tar recovery section. In addition, the value of the tar is low. This raises the point as to whether

or not fixation of the tar by gasification, thereby utilising it as a fuel, would or would not show an economic balance as against tar recovery with, in cases where required, re-incorporation of the tar in the gas at the furnaces. Thus another research problem would be the development of a suitable process for the fixation of tar in the vapour or gaseous state, or alternatively a system of recovering tar of higher quality.

(3) *General.*—Reviewing the situation generally as above, we have therefore the following questions to answer from the research angle :—

(*a*) What are the possibilities of improving present British practice by an investigation of the problems outlined and directed to the use of a wider range of coals on existing types of producers ?

(*b*) What advantage can be taken of continental developments in their application to British coals ?

(*c*) What advantage can be taken of the results of the study of combustion reaction kinetics which has led to the B.C.U.R.A. development in the so-called down-jet furnace, where combustion is effected by the introduction of the air blast on the surface of a fuel bed resting on a solid hearth, and where the ash is removed continuously in liquid form ?

(4) *Specific Items for Research.*—The following items of research are suggested as a means of answering the problems outlined above :—

(*a*) Distribution of the fuel charge in the producer in relation to the descent of fuel across the producer section and an investigation of the temperature, gas composition and distribution through the fuel bed.

(*b*) Clinker formation as influenced by the behaviour of freshly formed ash in various atmospheres and the possibilities of removal of ash in liquid form. Blast composition, temperature and distribution and the effect of preheat in conjunction with waste-heat recovery.

(*c*) Improvements in operation control by better instrumentation.

(*d*) Application of recent discoveries in combustion reaction kinetics combined with the study of activation.

(*e*) Fixation of tar in the vapour or gaseous state in the gas stream and methods of recovery of improved quality of tar.

Perusal of the literature on this subject shows a large amount of information of a fundamental character available on most of the items which have been mentioned for research. It seems that what is wanted is a more definite attempt to apply the results which have been obtained. Most of the improvements introduced in British practice have been of a mechanical nature, and more thought appears to be called for on the possibility of fundamental changes in design whereby the findings of research might be more satisfactorily applied.

Discussion

Mr. D. C. Gunn in a written contribution, gave particulars of a small fully-automatic gas producer capable of manufacturing raw producer gas from a wide variety of solid fuels. The capacity of the unit ranged from 12,000 cu. ft. of 130 B.Th.U. gas an hour made from 200 lb. of coke, to 14,000 cu. ft. of 160

B.Th.U. gas an hour made from 250 lb. of non-caking bituminous coal. The means adopted to maintain an even fuel bed by means of a levelling gauge controlling the coal discharge valve are of particular interest, as also is the rotating grate with ash discharge system automatically controlled by a thermocouple ; both these devices tend to maintain uniform working conditions in the producer by eliminating the human element to a large degree, and thereby assist in maintaining efficiency. The air blast is supplied with water vapour from an annular water jacket surrounding the lower part of the firebed. This producer has a maximum output of some 25 therms an hour and will deal with any fuel between charcoal (which is too light to stay on the bed) and a heavily caking coal.

Mr. J. W. Oliver wrote calling attention to the desirability of incorporating a suitable weight measure into the design of every producer in order that the fuel consumption needed for the day-to-day working of the battery might be ascertained.

He pointed out that the usual means afforded for the control of the air blast quantity left much to be desired. The means of control must be conveniently situated for the operator and easy to manipulate or they will be neglected. The position of the thermocouple elements for the measurement of the blast saturation temperature are also very important. The housings and design of the instrument should be such that it can only be inserted in the specific design position. The use of oxygen enrichment for burning out gas mains had possibilities provided that the quantity of oxygen admitted was adjusted so as not to damage the tube lining.

Mr. C. H. Williams wrote : I should like to lay stress on certain aspects—the training of operators, an improvement in their status, local improvements in the gas house which should be treated after the style of a power house, and the provision of means for correct control. The automatic regulation of coal feed was favourably mentioned by several speakers ; I had some share in the introduction in Great Britain of this particular form of control and in its subsequent development, and I can testify to its efficiency and simplicity, in conjunction with gas pressure (or gas " make ") and blast saturation it removes much of the hazard and guesswork which so often is the result of manual operation even with conscientious and trained operators.

Such controls in use on mechanically fed and agitated gas producers allow of efficient ratings of over 30 lb. per sq. ft. of firebed area, and with continuous ash removal the ratings are, as one speaker mentioned, up to 45 and 55 lb. Improvements now on the way in the mechanisms of gas machines will assuredly have important results in the efficiency and lower maintenance of producer plants.

A most important feature is the distribution of raw gas, and one which, to my mind, was insufficiently stressed. Gas mains can be and are being efficiently insulated in such a manner that the insulating properties of the linings are preserved : money is well spent in making a good job of this. The metering of raw gas has now been proved over several years ; this allows a check on the consumption of furnaces, and, equally important, on the automatic control of combustion. I have direct experience of three of the largest furnaces in this country using successfully this form of control on hot raw producer gas ; the newer forms of venturi system have overcome many of the earlier troubles encountered.

One of the drawbacks of raw producer gas that is often mentioned is the necessity of frequent shut-downs for burning out the gas mains. It still is not sufficiently appreciated that with modern designs of gas mains these shut-downs are now unnecessary. In the glass industry where continuity of gas supply is of the utmost importance there are certain works in Great Britain where development over several years has proved that raw producer gas can be supplied day in and day out not only over several weeks or months but over years of continuous operation. Such systems involve the use of steam lances and blowers.

With these methods in use, raw gas is used in the most efficient manner possible and with scientific control. Where gas cleaning is employed, the fuel is ideal for very delicate heating operations even in the smallest of furnaces.

It was surprising that two of the speakers laid more stress on what they considered disadvantages of producer gas as compared with other forms of heating than to the possibilities of improvements in the production of the gas and in its use. I must draw the conclusion that either the gas plants of which they had experience had not been brought up to date or that producer gas was being wrongly applied. I suspect the latter as being the prime reason for their comments. Where a process allows of the heat to be directly applied by solid fuel and use can be made of the heat in the products of combustion right down the temperature scale—as, for example, in a boiler fitted with an economiser or in some fairly low temperature chemical process—very little waste heat remains for preheating the combustion air. In such cases producer gas can usually show little advantage. When, however, the process demands that the products leave the furnace chamber at high or relatively high temperature, air preheat is a necessity for efficiency, and the combined thermal efficiency of the gas producer and the furnace is very much greater than can be obtained with direct firing with solid fuel. High air preheat can, and should, be used with gas, but it cannot be used with solid fuel. It must also be stressed that producer gas allows of better distribution of the heat in a furnace than solid fuel and of better control of furnace atmosphere. Such points must be carefully considered in making comparisons.

Mr. M. W. Thring wrote pointing out the advantages of using preheated air blast and referring to the remarks at this session by the Chairman, Mr. Gray and Dr. Seddon. He added : It is necessary, however, to sound a note of caution and indicate that the introduction of preheat of the air should be coupled with other modifications to present systems. This is because apart from defects of caking and non-distribution of special fuels, the major factor preventing improvements in producer performance is the necessity to limit the maximum bed temperature owing to the necessity to avoid excessive clinker in present designs. If preheat of blast to the producer could be introduced without increasing the amount of steam supplied to the producer, the result would be a tremendous gain in performance because not only would the calorific value of the cold clean gas rise but also the burden of undecomposed steam in the gas would be greatly reduced. On the other hand, where, with existing producers and fuels, the bed is already operating at the maximum permissible temperature, the introduction of preheat would mean that the steam injection would have to be considerably increased in order to maintain the same maximum temperature. Thus in Fehling's example the saturation temperature has to be raised from 45° to 60° C. when a preheat of 400° C. is introduced. Now when the steam injection is increased the improved calorific value is mainly an increase of the hydrogen content of the gas and there is a deep-rooted tradition in the steel and glass industries that hydrogen in the producer gas is undesirable. Moreover, the undecomposed steam in the gas would actually be increased if the bed temperature were maintained the same by introduction of additional steam.

It can, therefore, be concluded that the introduction of preheated air to gas producers must go hand in hand with the solution of the main problem which is at the moment confronting producer designers, namely, how to operate the producer without clinkering and yet have less undecomposed steam in the gas. There are two possible ways around this. One is to design an ash removal mechanism which will handle the ash produced in that awkward region where it is neither powder nor fully liquid but is more or less clinkered. The other is to carry forward the fundamental investigation of the reactions in the fuel bed to the point where it becomes possible to reduce the primary peak formation of CO_2 where the air first reaches the fuel and thus iron out the peak temperature in the bed so that the general temperature can be raised without clinkering.

As a third range suggestion for the improvement in the use of gas producers I would personally put forward the recommendation that recording calorimeters of a simple type, which have been tested and shown to be practicable in the trials carried out at United Steels should be installed in every large battery of producers, one to each battery, since this provides the basic link between the gas producer battery and the furnace operator and enables the manager to see at a glance when troubles in operation must be attributed to producer troubles. Later, perhaps, it will be possible to develop a recording calorimeter which gives the calorific value of the hot raw gas including the tar and the diluting water vapour.

Dr. F. A. Williams wrote summarising much of the information on German producer practice contained in the B.I.O.S. and C.I.O.S. reports. Few novel developments are recorded from Germany, but there is much information on the development and working of earlier processes. It has been found that amongst the outstanding gasification developments in Germany in recent years have been the use of oxygen in the blast, and ash removal from the generator as molten slag.

I.G. GENERATORS

The I.G. Farbenindustrie have operated Würth generators at Leuna with molten slag removal for many years, employing a blast consisting normally of air although oxygen-enriched air (24 per cent. oxygen) was also used under suitable conditions (C.I.O.S. Report XXXII—107, and B.I.O.S. 199).* The Würth generators have been progressively replaced since 1930 by generators designed by the I.G. of exceedingly simple design (Fig. 1 of B.I.O.S. 199) which employed brick lining only for the hearth and extreme top, the centre portion consisting merely of a water-cooled mild steel shell. The resulting reduced insulation as compared with the Würth generators made it difficult to run on air alone, and water gas containing a high proportion of CO was normally made using a mixture of oxygen and steam which gave temperatures sufficiently high (about 1700° C.) to ensure fluxing of the ash.

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* References are to published reports of the Combined Intelligence Objectives Sub-Committee, the British Intelligence Objectives Sub-Committee and the Field Information Agency (Technical), which are obtainable from His Majesty's Stationery Office.

These generators are capable of gasifying a wide variety and size of fuels provided they are larger than 30 mm. It is stated that pieces 1 to 2 ft. in size can be employed. The fuels used range from metallurgical coke, carbonised brown coal briquettes ("Grude") and "Rohschlacke" containing 50 per cent. of carbon from the grates of "Make and Blow" water-gas generators working on Ruhr coke at high outputs. To assist in fluxing the ash, 3 per cent. of limestone and 20 per cent. of slag were added when using metallurgical coke.

Typical operating figures for I.G. generators are given below :—

	"Rohschlacke"	"Grude" from Deuben	Met. coke	Met. coke with CO_2 in blast
	Per cent.	Per cent.	Per cent.	Per cent.
CO_2	9·7	5·4	6·8	3·0
CO	66·5	62·4	61·4	92·5
H_2	22·9	31·2	31·0	3·0
CH_4	nil	nil	nil	nil
N_2	0·9	1·0	0·8	1·5
H_2S, g/m³	2·7	13	4·3	2·2
O_2, m³/m³ $H_2 + CO$	0·347	0·276	0·262	0·310
H_2O, kg/m³ $H^2 + CO$	0·207	0·266	0·346	nil
CO_2, m³/m³ $H_2 + CO$	nil	nil	nil	0·258
Fuel, kg/m³ $H_2 + CO$	?	0·80	0·490	0·530
Carbon, kg/m³ $H_2 + CO$	?	0·482	0·424	0·460
Fuel analysis, C	45–50	54	86·8	87·2
Ash	55·40	16·9	9·1	11·8
H_2O	nil	22	1·8	1·0

The last column illustrates the results of replacing steam in the blast with CO_2—an investigation to which I.G. had devoted much attention.

In general the I.G. were of the opinion that in common with other oxygen-gasification processes, the slagging generator was only an economic proposition when using cheap fuels which could not be gasified in other ways, e.g. small fuel, fuel of high ash content and fuel of low melting-point ash.

THYSSEN-GALOCSY GENERATORS

Although in 1943 the T.G. process had been developed to a stage where a single generator was erected at Wanne-Eickel to gasify 40 tons of fuel per day (C.I.O.S. XXIX—51) it cannot be regarded as so fully developed as the I.G. generator.

The most important differences from the I.G. design lie in the use of a generator of much greater height, brick-lined throughout and containing in the upper part an inner empty steel shaft. Three sets of tuyeres are provided at the base, the bottom set serving to burn a mixture of a suitable fuel gas with oxygen and steam whilst one of the two upper sets was used to introduce more oxygen. It seems possible that when fully developed the generator may be able to dispense with some of the tuyeres by ensuring intimate mixing of the gases prior to entering the generator—a point on which I.G. lay much emphasis.

Wartime difficulties had prevented any trial of the generator longer than four weeks. It was, however, claimed that coke 30–60 mm. in size could be successfully gasified but it was necessary to employ a temperature some 300° C. higher than the melting point of the ash. Operation on oxygen and not air seems, therefore, to be essential.

It was reported that it was hoped to gasify 3–5 mm. coke breeze and arrangements were in hand to test the use of a hard coal.

The available figures for short-term runs show a similar carbon consumption to the I.G. generator but a higher oxygen consumption and in practice it appears to be some 50 per cent. higher than that quoted in pre-war reviews.

PINTSCH TYPE OF SLAGGING GENERATOR

The gas plant at the Scholven hydrogenation plant was found to contain eight Pintsch generators each with a capacity of 8,400 m^3 per hour of water gas but employing liquid slag removal. The generators operated on a three-minute cycle using an air blast only. From the information so far available it appears that the efficiencies of these generators are no higher than can be obtained on non-slagging " Make and Blow " generators. The generator does, however, afford a way of utilising hard coke of low ash-melting point which would cause trouble with clinkering in ordinary water-gas generators.

WINKLER GENERATORS

The Winkler generator is now well established in a number of factories in Germany and it was, in fact, the first type of oxygen generator to be fully developed (B.I.O.S. 199).

The general principle of the generator using a " boiling bed " of fine fuel was well known before the war and very complete descriptions are now available (C.I.O.S. XXXII—92, C.I.O.S. XXXIII—24, B.I.O.S. 333). The fuels employed are dried brown coal and carbonised brown coal or " Grude " which are particularly reactive as well as cheap. At Leuna, Winkler generators of identical design are used to make both producer gas and water gas and the output of one generator of producer gas may be as high as 40,000 to 70,000 m^3 per hour using air as blast. Water gas production entails a blast of steam and oxygen (40–50 per cent.) and yields up to 60,000 m^3 per hour.

Although in commercial use, the generator has been undergoing constant development. Particular attention has been paid to the design of the grate and its scraper and the latest improvement has been the development of a grateless generator.

Although the bulk of the blast is introduced at the extreme bottom of the generator, whether or not a grate is employed, a certain amount of air or oxygen is always introduced at a point above the fuel bed. This is intended to burn off some of the finely divided fuel blown out of the bed and also to raise the temperature of the gases so that further cracking of tar or hydrocarbons may occur. For many power-gas requirements the presence of a small amount of hydrocarbon may not be objectionable.

Performance details of the Winkler generator are given below :—

	Leuna Power gas (12 months av.)	Leuna Water gas (12 months av.)
Actual output, Nm^3/hr.	50,000	27,000
Fuel	Dry brown coal	Dry brown coal
Analysis on dry basis—		
C	57·8	59·3
H	4·3	4·5
O	16·5	15·2
N	0·6	0·7
S	3·3	3·6
Ash	17·5	16·7
H_2O	(8·5)	(8·7)
Cal. val. T. cals./T. net as received	5,109	5,170
Gas analysis—		
CO_2	9·8	21·8
CO	21·7	35·3
H_2	11·7	38·5
CH_4	0·7	1·8
N_2	55·3	1·1
H_2S	0·8	1·5
Cal. val. k.cals./Nm^3	984	2,117
Blast above fuel bed	25 per cent.	—
Fuel bed. temp.	950° C.	—
Gas exit temp.	1000° C.	—
Dust content of gases in g/Nm^3 dry gas	65	110
Per cent. C in dust	35–55	29
Per cent. C in ash	34–44	42
	Efficiencies/1,000 m^3 *gas*	*Efficiencies*/1,000 m^3 $H_2 + CO$
Fuel, kg.	330	830
Carbon, kg.	176	452
Air, m^3	700	366 (Oxygen)
CO_2, m^3	25	407 (steam used)
Steam raised, kg.	450	600
Carbon utilisation, per cent.	83	86·5
Dust blown over, kg.	65	148
Grate ashes, kg.	18	41
Power kWh	—	48

As might be expected on account of the carry-over of dust, the thermal efficiency of the Winkler generator is no higher than that of the conventional water gas generator.

As far as could be ascertained, no large Winkler generator has been run for any length of time on bituminous coal dusts to produce water gas, although experimental work has been carried out on a small generator (0·8 m^2 shaft area) at Oppau, and in a larger generator (2 m^2 shaft area) at Leuna and it is said that bituminous coal, low-temperature coke and even anthracite can be employed. Since such fuels are appreciably less reactive than brown coal or brown coal coke, it is necessary to work at higher temperatures, which means higher oxygen consumptions, etc., and consequently increased costs. Owing to the higher temperature the secondary air or oxygen supply tends to react with the gas rather than with the dust in the space above the fuel bed. It would seem that although certain of the non-caking coals in this country and low-temperature-coke breeze might on account of their reactivity be successfully gasified in Winkler generators, such fuels are rarely as cheap as brown coal and this is likely to prohibit the use of such generators for water gas. Preheating of the gasification mixture in order to reduce oxygen costs was apparently under consideration at Leuna (B.I.O.S. 199).

NON-SLAGGING WATER GAS PRODUCTION USING OXYGEN

A recent development (1938) by the I.G. (B.I.O.S. 199) has been the application of oxygen-steam mixture containing not more than 16–17 per cent. oxygen to the gasification of hard " grude " in generators of the normal water-gas type but operated continuously and without slagging. I.G. were sufficiently satisfied with the control of the process by 1941 to decide to instal plant for the gasification in this way of bituminous coal semi-coke at Auschwitz.

GENERAL CONSIDERATIONS REGARDING OXYGEN GASIFICATION

From the study of actual operating records in Germany it is clear (B.I.O.S. 591) that the lowest energy costs for oxygen production were realised at Leuna, viz. 0·65 to 0·68 kWh per m^3 of 100 per cent. oxygen. Even at these figures oxygen gasification is not economic unless fuel costs are very low. The general position regarding oxygen gasification is critically reviewed in B.I.O.S. 199. In particular, the position regarding hard coke is that slagging generators are not so economic as " Make and Blow " water-gas generators although somewhat more economic than non-slagging generators using oxygen.

OTHER GASIFICATION PROCESSES

PINTSCH-HILLEBRAND

The Pintsch-Hillebrand process for manufacturing water-gas from brown coal briquettes was well known before the war. As a result of the investigation of the Wesseling hydrogenation plant (C.I.O.S. XXVIII—40, C.I.O.S. XXVII—60, F.I.A.T. 425) further details of operating data, etc., have been obtained. In particular it is clear that the quality of the briquettes is a most important factor in smooth operation.

WINTERSHALL-SCHMALFELDT PROCESS

The Wintershall-Schmalfeldt process (C.I.O.S. XXXII—90) although ultimately leading to the production of synthesis gas is interesting however in so far as it employs in one stage the gasification of brown coal in a gas-borne condition in a mixture of preheated air and steam. The W.S. process as a whole appears to have been very unsatisfactory and to have given rise to many troubles, apart from inherent difficulties such as that of high fuel consumption due to the loss of ungasified dust in both the producer-gas stage and in the synthesis gas stage. With bituminous coal the losses would probably be even greater.

Dr. F. Johnstone wrote : In the course of various nitration processes, notably in the production of nitrocellulose, waste mixtures of sulphuric and nitric acids are produced. In the recovery of these, nitric acid is first removed by a denitration process leaving weak sulphuric acid of about 68 per cent. strength. This acid is then concentrated by heating in a cast-iron pot of about 14 tons sulphuric acid capacity with mechanical agitation. The acid is fed through a dephlegmating column where partial concentration takes place and sulphuric acid is removed from vapours ascending the column ; 95 per cent. sulphuric acid leaves the pot continuously at about 300° C. and then passes through a cooler to storage. The entire pot is set in a combustion chamber which hitherto has been fired either by hot raw or cold clean producer gas, one producer serving a battery of pots.

Whilst giving some advantage in thermal efficiency, the use of hot raw producer gas necessitates a complete shut-down for the greater part of one shift per week for cleaning gas mains, and this naturally limits output and increases operating costs. Although this objection is eliminated by the use of cold clean producer gas, the higher consumption and price of coke per unit of production has to be taken into account.

During recent months, trials have been carried out with underfeed stoker firing in place of producer gas. The firebrick arch below the pot was removed in the earlier stages of the trial, but was replaced later in an endeavour to prolong the life of the pot. The coal and air fed are automatically controlled from the combustion chamber temperature. No difficulty is experienced in controlling this temperature to within ± 10° C. at 1000° C. Water sprays have been fitted below the grate to eliminate ash fusion troubles experienced with certain consignments of coal, although when using Mauchline (Ayrshire) washed singles, little trouble is experienced. The water supply to the sprays is, of course, linked up automatically with the intermittent operation of the stoker.

In addition to the elimination of heat losses in external gasification of the fuel arising from the use of producer gas, one of the outstanding advantages associated with the underfeed stoker is the increase in acid throughput now possible as compared with gas firing. Since all other operating temperatures must of necessity be the same in the two processes, this can only be attributed to an increase in the overall rate of heat transfer, believed to be due to an increase in the ratio of radiant to convective heat transfer from direct as compared with gas firing. There is also a considerable improvement in the overall thermal efficiency of the plant which is increased from about 39 per cent. to 60 per cent. in the changeover to direct firing.

Our experience up to the present suggests that the pot life may be reduced with direct firing, but even so, with the present price of coal, the process is economic. It is hoped that the recently constructed arch will so prolong the life of the pot as to enhance further the advantages of direct stoker firing.

A thermal balance sheet is given below, and the percentages are shown diagrammatically in Figs. 25a and 25b.

	Hot raw producer gas			*Underfeed stoker*	
Heat input		per cent.			per cent.
Steam		3	Coal		100
Coal		97			—
		100			
Heat output—					
Sensible heat of product (H_2SO_4)	10·5			16	
Heat of concentration	6·5			10	
Vapour to condenser	22·0	39·0		34	60·0
Losses—					
Flue gas	30·0			25	
From conc. plt.	11·0			14	
In gasification	20·0	61·0	In ash	1	40·0
		100·0			100·0
Thermal efficiency		39·0			60·0
Sulphuric acid (as H_2SO_4) concentrated per ton of coal used—		6·0			9·3

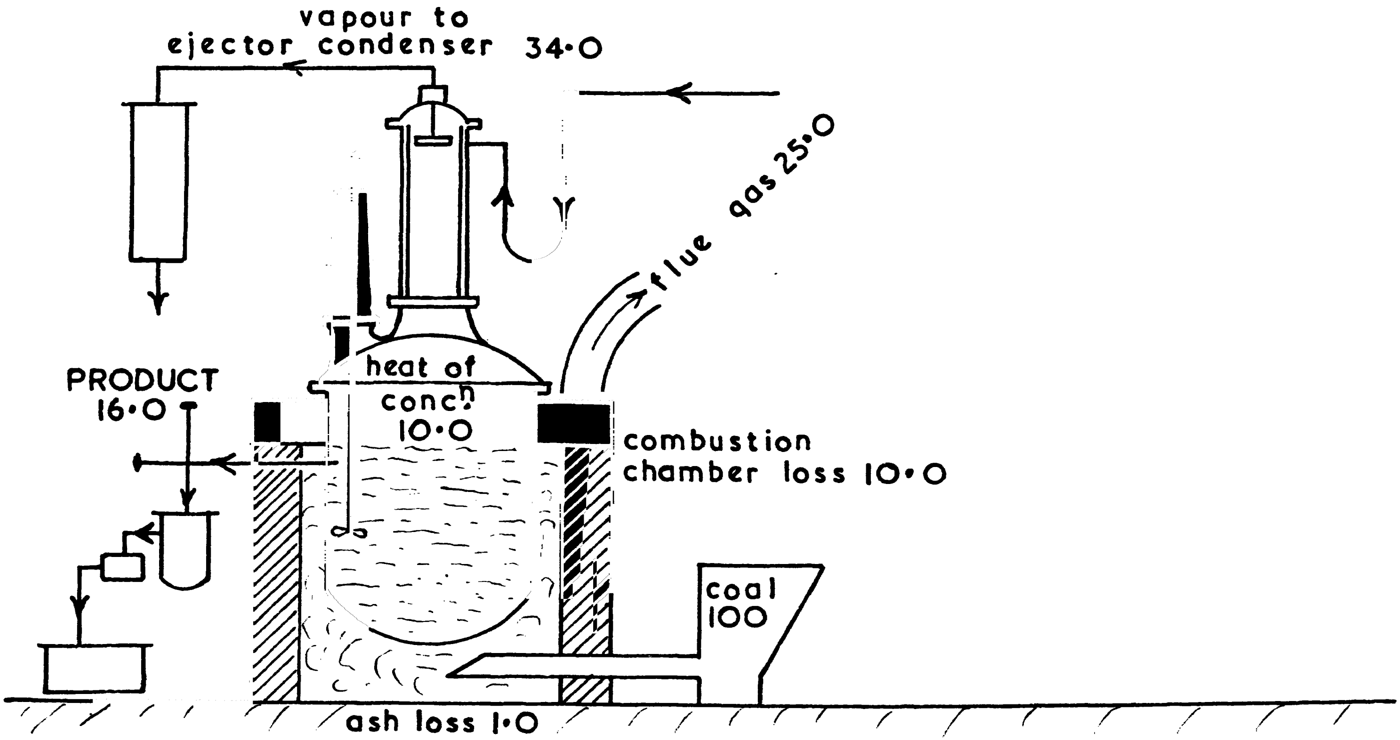

FIG. 25a. Sulphuric Acid Concentration—Direct Firing by Underfeed Stoker.

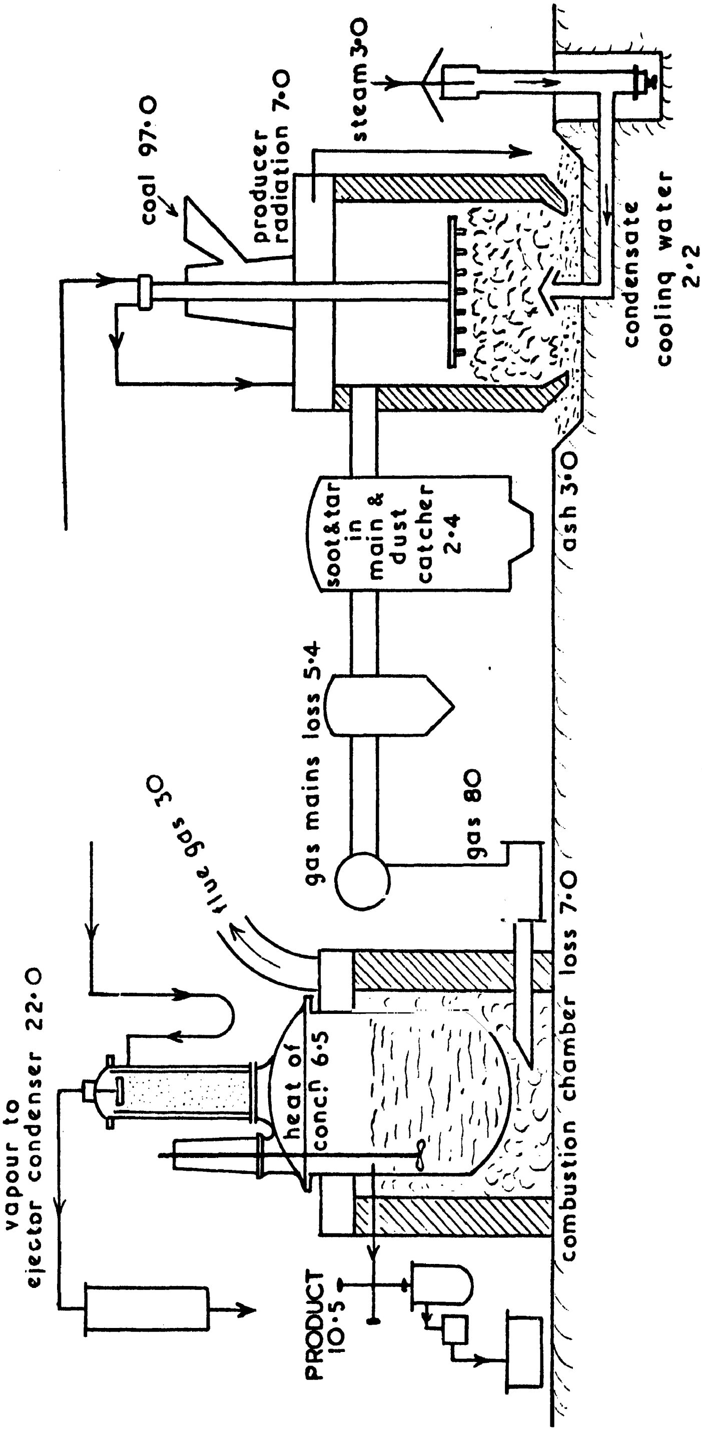

Fig. 25b. Sulphuric Acid Concentration—Producer Gas Firing.

SECTION D.
HIGH TEMPERATURE PROCESSES—*continued*

SESSION IIIb. Oil Firing

Chairman of Session: DR. F. H. GARNER, O.B.E.
PROFESSOR OF OIL ENGINEERING AND REFINING, BIRMINGHAM UNIVERSITY

THE CHAIRMAN, in opening the proceedings, said that the imperative need today was to use less coal and to promote the maximum efficiency in the use of all fuels. The main attention must be directed to the right use of different types of fuel. The replacement of coal by fuel oil did not necessarily result in an economy in fuel, but the higher calorific value of fuel oil and ease of handling a liquid as compared with a solid must be taken into account.

An important question was that of availability for ordinary use and here coal had a special importance in this country. An interesting example was afforded quite recently in which coke produced by the cracking of high-sulphur crude petroleum had accumulated in very large quantities in California owing to the fact that no one could be found to use it. It was unsaleable although of quite high calorific value. This fuel had lately been transported for use in Germany and elsewhere for burning either by itself or mixed with lower sulphur content fuels.

1. Liquid Fuel for High Temperature Processes*

(*abridged*)

By T. C. BAILEY, F. J. BATTERSHILL and R. J. BRESSEY

INTRODUCTION

High-temperature processes constitute the most important field for fuel oil. Care must be taken to choose the right fuel for the job. The special features of oil fuel described in this paper appeal particularly to such basic industries as iron and steel and non-ferrous metals. There are many successful applications of oil outside the high temperature field to which no reference will be made here. Oil fuel used in the quantities visualised by the present campaign will supply only some 3 or 4 per cent. of the total therms required in this country, but it is most important nationally that it should be used to the best advantage.

CHARACTERISTICS OF LIQUID FUEL

" Crude oil " is the liquid which comes direct from the oil wells ; " heavy fuel oil " and bitumen are left after distillation of this crude oil into various commercial products. Table I gives approximate specifications for three typical heavy fuel oils, (*a*) and (*b*) being the Pool grades at present marketed by the Petroleum Board in the United Kingdom, and (*c*) being a typical heavier grade that may become available in the future.

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* Published in full as a supplement to the Institute of Petroleum Review, January, 1947.

Table I

APPROXIMATE SPECIFICATIONS OF FUEL OILS

	(*a*) Pool fuel oil	(*b*) Pool heavy fuel oil	(*c*) A 1,500 sec. fuel oil
Specific gravity at 60° F.	about 0·935	about 0·95	about 0·96
Flash point (closed) ° F. minimum	150	150	150
Viscosity Redwood I at 100° F., seconds	220 max.	950 max.	1,500
Gross calorific value B.Th.U./lb.	about 18,900	about 18,750	about 18,700
Gross calorific value, therms/gallon at 60° F. (approx.)	1·77	1·78	1·80

Fig. 26 shows the effect of temperature on the viscosity of fuel oils. By preheating, the more viscous grades can be reduced to the same viscosity as the thinner ones. Having determined the viscosity required for easy pumping and that required for correct atomisation, the temperatures to which the oils must be heated can be read off the viscosity chart.

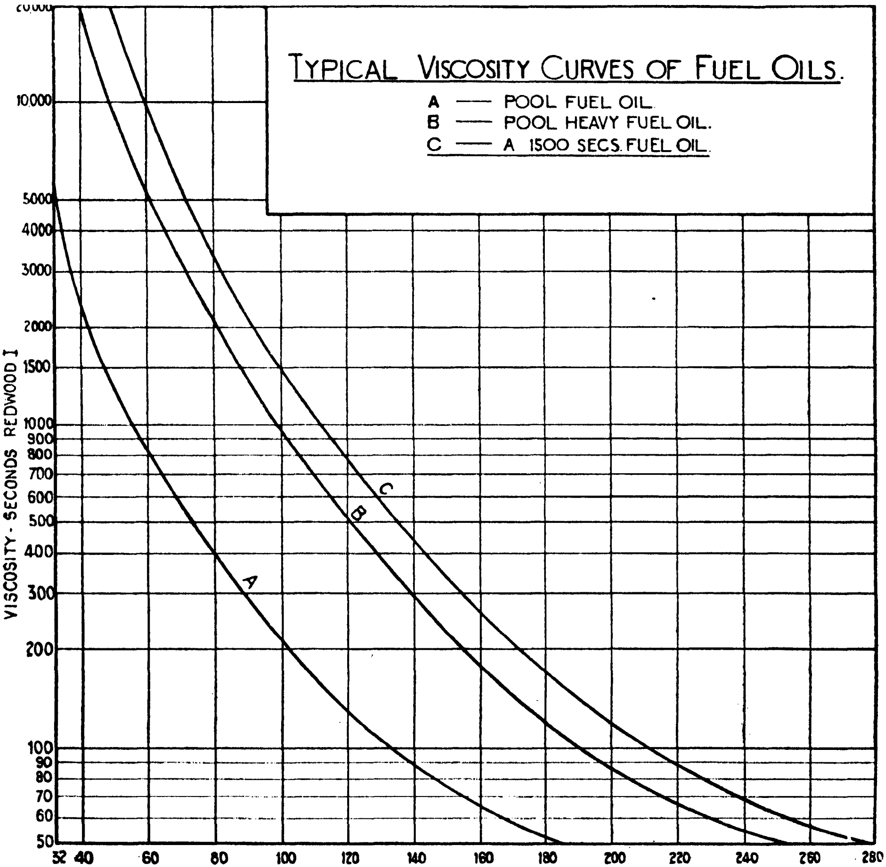

Fig. 26.

DELIVERY, STORAGE AND HANDLING OF LIQUID FUELS

This subject will not be treated in detail here, since it is dealt with at length elsewhere.[1, 3]

Storage tanks should be installed above ground wherever possible and should be equipped with thermostatically-controlled steam coils or electric immersion heaters to maintain the oil at a temperature at which it will be easy to handle. Transfer of the oil to the burners should nearly always be done by means of a ring main through which the oil is pumped and returned to pump suction and/or storage tank. The oil is heated before reaching the burners to reduce its viscosity so that it can be " atomised " and burnt properly. The preheating of the oil for burning may be carried out (*a*) immediately after the pumps or (*b*) as close to the burners as practicable. If method (*a*) is adopted the oil will be circulated at the burning temperature whereas in case (*b*) the oil will be circulated at storage temperature.

Table II gives particulars of recommended approximate storage temperatures and, although no hard-and-fast rule can be laid down, indicates the limits within which the right temperature of preheat at the burners will probably be found to lie. With pressure-jet burners the lower limit of the temperature range will be about 20° F. higher and the upper limit about 50° F. higher.

TABLE II

Grade	Recommended minimum temperature in storage tank	Oil temperature at burners
	° F.	° F.
(*a*) Pool fuel oil	45	110–140
(*b*) Pool heavy fuel oil	70	170–200
(*c*) 1,500 sec. fuel oil	80	190–230

OIL BURNERS

All the oil-burning appliances used for high-temperature processes work on the principle of forming a fine spray or mist of oil particles, each of which can come into intimate contact with the combustion air. This is generally known as " atomisation ". Home-made makeshift burners should *never* be used.

Burners may be classified according to the method adopted for atomisation,[3] namely :—

(i) Pressure jet.
(ii) Blast atomising type—
  (*a*) Air jet, including low-pressure, medium-pressure and high-pressure air.
  (*b*) Steam jet.

With air-jet burners, the lower the air pressure used the larger will be the volume to be passed through the burner for atomising purposes. For example, a high-pressure burner using air at 50 lb./sq. in. will only need about 2·5 per cent. of the total combustion air for atomising purposes, while a low-pressure air burner working at 1 lb./sq. in. (28 in. w.g.) will need about 20 per cent. of the combustion air for atomisation. Moreover, since air passing through a burner should not be preheated above 500° F., it follows that the use of low-pressure air burners for high-temperature processes, where the maximum use must be made of recuperators and regenerators to ensure economy and the high flame temperatures necessary, is rather restricted ; high-pressure air-jet burners are, thus, generally recommended for this class of work. The full degree of preheat can then be applied to 97–98 per cent. of the combustion air. In general, steam atomisation is not recommended for furnace work because it results in a slightly lower flame temperature. There are, however, special cases where a high pressure atomising medium is required and steam is used because it happens to be readily available at low cost.

AIR SUPPLY

The means of providing the correct amount of air for the combustion of fuel oil is an important part of an oil-burning plant. Each pound of oil will theoretically require about 180 cu. ft. of air for complete combustion and, if efficient furnace performance is to be obtained, every effort should be made to achieve clean combustion conditions with as small an excess over this quantity as possible. Table III gives the CO_2 content of the products of combustion of a typical heavy fuel oil with various percentages of excess air, and other useful data.

TABLE III

EXCESS AIR AND CO_2 FIGURES

Excess air per cent. by volume	CO_2 in dry products of combustion per cent. by volume	Actual air supplied per lb. of fuel cu. ft.	Volume of wet products of combustion cu. ft.
0	16·0	181	192
10	14·5	199	210
20	13·2	217	228
30	12·1	236	246
40	11·2	254	264
50	10·4	272	283
60	9·8	290	301
70	9·2	308	319
80	8·6	326	337
90	8·2	344	355
100	7·8	362	373
150	6·2	453	464
200	5·1	544	554

Note.—The gas volumes are at 60° F. and 30 in. Hg., air assumed to be dry.

It should be the aim of every oil user to work as closely as possible to the ideal of 16 per cent. CO_2 unless, of course, the furnace conditions demand otherwise.

The ability to burn oil with low excess air generally depends on three factors :—

(i) Good atomisation of the oil.

(ii) Highly preheated air.

(iii) Means of ensuring that the air is admitted correctly as regards place, direction and amount relative to the stages of combustion, so that intimate mixing of air and atomised oil takes place as required.

All the air for combustion should be under control. Valves should be used for regulating a high or medium-pressure air supply to burners, and slide or butterfly dampers for controlling a low-pressure air supply, whether to burners or secondary air ports. Controls should be so designed that fine adjustments can be made, and should be marked, or fitted with indicators, so that predetermined settings can be readily obtained. In the great majority of high temperature furnaces 97–98 per cent. of the combustion air will be highly preheated ; this will not be taken through the burners, but introduced as secondary air. It is important that the secondary air admission ports should be designed and located so that the air mixes intimately with the stream of oil particles. Well designed ports can make a considerable contribution to high furnace efficiency.

ADVANTAGES OF LIQUID FUEL

The general advantages of oil as a fuel may be summarised as follows :—

(i) Uniformity of quality.
(ii) Cleanliness.
(iii) Ease of storage.
(iv) Saving of labour.
(v) Controllability and flexibility.
(vi) Facility in handling.
(vii) Absence of ash.
(viii) High flame temperatures.
(ix) Luminous flames.
(x) High furnace efficiencies.
(xi) Greater outputs from furnaces.

High flame temperatures.—Table IV gives the approximate theoretical flame temperatures for various fuels burnt with no excess air and no preheat, allowing for dissociation.

TABLE IV

FLAME TEMPERATURES

Fuel	Flame temperatures	
	° C.	° F.
Fuel oil[2]	2080	3780
Coal gas	2045	3710
Producer gas[3] . . .	1600	2910
Blast furnace gas[3] . . .	1460	2660

In order to make a comparison of flame temperatures under working conditions, Fig. 27 has been prepared for fuel oil and producer gas, each assumed to be burnt with 20 per cent. excess air and with varying degrees of preheat on the air and gas. It will be seen that while preheating does narrow the gap between the fuels, the margin in favour of oil remains substantial.

In order to demonstrate the great significance of high flame temperature in securing high rates of heat transfer, Table V has been prepared. To make comparisons on some sort of practical basis, it has been assumed that the fuel oil is burnt with 20 per cent. excess air, preheated to 900° C., and that the producer gas is also burnt with 20 per cent. excess air, both gas and air being preheated to 900° C.

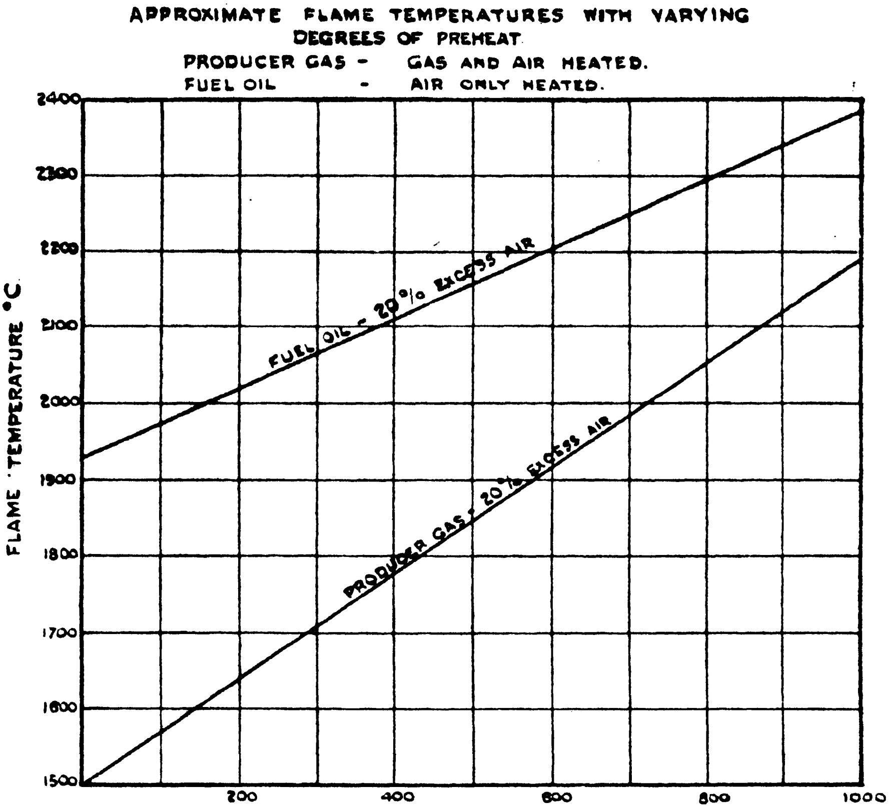

Fig. 27.

The Stefan-Boltzmann law may be put into the form :—

Heat radiated $= 1730 \times E \times (T_1^4 - T_2^4) \times 10^{-12}$ B.Th.U. per sq. ft. per hour.

Where T_1 = Flame temperature in ° F. absolute.

T_2 = Working temperature in ° F. absolute

and E is a function of the emissivity of the flame (E_1) and that of the receiving body (E_2). E_2 need not be considered further here as, for given working conditions, its value can be assumed to be substantially the same irrespective of the fuel used.

TABLE V

COMPARISON OF RADIATING POWER OF FUEL OIL AND PRODUCER GAS FLAMES

	Fuel oil	Producer gas
Flame temperature ° C.	2340	2120
Flame temperature ° F. absolute (T_1)	4700	4310
	$[(T_1^4 - T_2^4) \times 10^{-12}]$	
Where T_2 = 1930° F. absolute (800° C.)	474	331
Where T_2 = 2290° F. absolute (1000° C.)	460	318
Where T_2 = 3010° F. absolute (1400° C.)	406	263
Where T_2 = 3370° F. absolute (1600° C.)	359	216

This table makes it abundantly clear that, for high temperature processes, a fuel oil flame has a greater ability to transfer heat by radiation than a producer gas flame. It will be seen, in fact, that its ability is over 60 per cent. greater where really high working temperatures, of the order of 1600° C., are concerned.

Luminous flames.—The foregoing discussion regarding flame temperatures has disregarded the emissivity factor E_1, but as this varies with the fuel, and is of great practical importance, it must be taken into consideration when comparing fuels. Unfortunately, however, it cannot yet be evaluated by calculation as can the flame temperature. Practical furnace operators have long known that for many heating processes the transparent flames from certain gases are not conducive to quick and satisfactory heating, and have been seeking a more " solid " and effective flame. It is now known that high-temperature luminous flames provide just what the practical operator wants, but there still remains a considerable amount of research to be done to put the whole subject on a scientific basis.

It is well established that glowing particles of carbon cause the flame to become opaque and luminous, and that fuels which burn without such carbon particles tend to be transparent and non-luminous. This statement is supported by the fact that coke-oven gas burnt without preheating produces a non-luminous flame, whereas when preheated to high temperatures the hydrocarbons it contains decompose and carbon particles are formed which become incandescent and give rise to some luminosity. Unfortunately, however, the calorific value of the gas is reduced at the same time, and this probably counterbalances the advantage gained by luminosity. Raw producer gas, on the other hand, owing to its tar content, produces a more luminous flame than other gases.

A. J. Fisher of the Bethlehem Steel Corporation[4] endeavours to assess the luminosity values of fuels on the basis of their luminosity-producing carbon contents, and some of his figures are reproduced in Table VI. T. F. Pearson, in a recent paper on " The Problem of Flame Radiation "[5], suggests the classification of fuels on the basis of the weight ratio between " luminosity carbon " and hydrogen, the former term covering free carbon, plus carbon obtainable from tar vapours and hydrocarbons, but not from any other source such as CO_2 or CO. Some of his figures are also given in Table IX.

TABLE VI

FLAME LUMINOSITY

Fuel	" Luminosity carbon " (Fisher)	" Luminosity index " (Pearson)
Fuel oil	44·5	6·08
Producer gas, high tar		2·06
Producer gas, low tar	7·02	1·68
Producer gas and coke-oven gas 5 : 1 and 8 : 1		1·655
Coke-oven gas	20·5	1·62
Blast-furnace gas and coke-oven gas 2 : 1		1·56
Blast-furnace gas		0·00

Pearson's classification appears to agree better with practical observations than that given by Fisher. Both investigators, however, agree that, due to the presence of carbon particles, liquid fuels have a greater ability to produce luminous flames than gaseous fuels. These carbon particles, being solids, radiate heat according to the Stefan-Boltzmann fourth-power law. Radiation from transparent gases does not follow this law, but is proportional to a lower power of the absolute temperature. In fact, the only gases which contribute a serious quota of radiation under furnace conditions are carbon dioxide and water vapour ; the contribution of other gases such as nitrogen, hydrogen and oxygen is negligible. Taking into account the luminosity of the flame, therefore, it would seem that the radiating ability of a fuel-oil flame is even greater in comparison with that of a producer-gas flame than is indicated in Table V.

It is hoped that further research will throw more light on the subject of flame luminosity. Enough is known already, however, for it to be confidently asserted that the highly luminous flames from fuel oil are particularly advantageous where high rates of heat transfer by radiation are required and are superior in this respect to gas flames. Numerous examples in support of this statement could be quoted, such as the many instances where oil is injected into gas flames in order to improve them and the way in which oil is ousting gaseous fuels in the U.S.A. for steel melting in open-hearth furnaces.

Fisher, using a conventional total radiation pyrometer with a mica screen, the results being recorded on an arbitrary scale 0–100 and quoted as luminosity factors, demonstrated that, all other conditions being equal, furnace output depends very largely on flame radiation.

High furnace efficiencies.—Having accepted the technical advantages of fuel oil set out in the preceding paragraphs, the industrialist will not be able to form his final opinion until he can make some estimate of how the consumption of fuel oil will compare with that of other fuels ; the question of furnace efficiencies must, therefore, be dealt with. In the following comparison we have assumed that coal is burnt in probably its most common form for high-temperature work, viz., producer gas. Table VII sets out the percentage of the gross calorific value of fuel oil and of producer gas which is potentially available for use within the furnace at various temperatures. These percentages represent the limiting efficiencies of the fuels with no heat losses from the furnace. Waste-heat utilisation by means of regenerators or recuperators would, of course, improve the results on both fuels, and would narrow the gap between them. Given the same conditions, however, for excess air and waste-gas temperature, the same percentage of waste heat returned by the regenerator or recuperator, the percentage of gross heat input potentially available in the furnace will always be greater in the case of fuel oil than in that of producer gas.

TABLE VII

HEAT POTENTIALLY AVAILABLE FROM FUEL OIL AND PRODUCER GAS

Temperature of gases leaving furnace	Heat potentially available	
	Fuel oil	Producer gas
	Per cent.	Per cent.
800° C.	62·4	55·3
1000° C.	53·5	44·4
1200° C.	43·6	33·1
1400° C.	34·2	21·7

Note.—These figures are calculated on the basis of complete combustion with the theoretical amount of air—no preheat.

Assuming that 45 per cent. of the heat in the gases leaving the furnace is returned as preheat, the percentage of available heat (where gases leave at 1400° C.) then becomes 63·8 per cent. for fuel oil and 57·1 per cent. for producer gas. To complete the picture, the analysis should be taken one step further, i.e., back to the original raw fuel. The figure for oil then remains unaltered—whereas that for producer gas must be corrected by a factor for the producer efficiency. If this efficiency is taken at 80 per cent., the figure for producer gas then drops from 57·1 per cent. to 45·7 per cent. To state this comparison in another way—for every therm given up in the furnace for a process requiring the gases to leave at 1400° C., the theoretical heat consumption is 1·57 therms of oil or 2·19 therms of raw coal, or approximately one pound of oil against 2·00 pounds of raw coal. This conclusion is in line with the results obtained in various industries. In the case of glass melting in regenerative furnaces, W. A. Moorshead[6] also draws the same conclusion, i.e. that one pound of oil will do the work of two pounds of coal.

Greater outputs from furnaces.—In the majority of high-temperature processes, greater outputs can be obtained from furnaces fired with oil than from similar furnaces fired with coal or producer gas. This is not difficult to understand in view of the high rates of heat transfer obtained from the luminous high-temperature flames of fuel oil. The consistent quality of oil also plays its part by giving the unvarying conditions which are conducive to continuous output at maximum rates.

HIGH TEMPERATURE PROCESSES FOR WHICH LIQUID FUEL IS USED

The value of the advantages of oil will necessarily vary from industry to industry and from process to process, but that they have been appreciated over a very wide field of application will be clear from the following list which does not purport to be exhaustive, but it is fairly representative ; examples of practically every type quoted are successfully operating in this country today. For convenience the processes have been grouped under a few broad industry headings :—

Iron and steel.—Open-hearth furnaces, soaking pits, reheating furnaces. Plate, bar and billet heating. Rotary melting furnaces. Welding furnaces for tube making, etc. Bolt and nut furnaces.

Non-ferrous furnaces.—Smelting and refining, crucible and open flame furnaces for melting, billet heating.

Vitreous enamel.—Reverberatory and rotary frit-melting furnaces, enamelling muffles.

Glass.—Melting in tank and pot furnaces. Glory holes. Pot arches.

Clay.—Beehive and tunnel kilns for refractories, bricks, tiles, pottery, etc. Sillimanite calcining, enamel melting.

Miscellaneous.—Cement kilns, lime kilns ; gypsum calcining, alumina calcining.

The scale on which fuel oil is used in this country for these processes at present varies greatly. It can be safely asserted, however, that in many of them there is great scope for development in the use of oil, and this probably applies with particular force to the Iron and Steel, Glass and Clay industries. To conclude the paper, some brief notes are given on the application of oil to a few of the processes listed above.

Open-hearth furnaces.—The steel industry is displaying considerable interest in the oil firing of open-hearth furnaces as a result of the widespread use of oil for this purpose in the U.S.A. It is true to say that oil has very largely ousted producer gas in America, even where cheap and good coal is available. The principal advantages gained by the use of oil are :—

(i) Greater output from furnace (up to 30 per cent. increase).
(ii) Longer furnace life.
(iii) Simpler furnace construction.
(iv) No slag foaming.
(v) Lower labour costs.
(vi) No producer maintenance or burning out of gas mains.

Although the use of oil in open-hearth furnaces in this country is still in its experimental stage and the furnaces have been converted from gas firing and not designed for oil, the results to date are very encouraging. Table VIII indicates the fuel consumptions that are being obtained.

TABLE VIII

OIL-FIRED OPEN-HEARTH FURNACES

	(1)	(2)
Furnace capacity	150 tons	100 tons
Type of charge	66 per cent.	60 per cent.
Number of charges/week (hot metal)	9	12
Oil/ton ingots—single charges	31 gallons	28 gallons
Oil/ton ingots—overall, including maintaining over weekends	33 gallons	30 gallons
Gross B.Th.U./ton ingots—single charges	55 therms	49·7 therms
Gross B.Th.U./ton ingots—overall	58·5 therms	53·3 therms

It must be emphasised that these fuel consumptions are from furnaces that have really only been " patched-up " for oil firing and not from furnaces specially designed for this fuel, such as there are in the U.S.A. Nevertheless, each ton of oil burnt is doing the work of about two tons of producer coal. It is hoped that as more open-hearth furnaces are converted, full details of the results on oil will be published.

The burners used for these furnaces, both here and in America, are generally of the steam-jet type. Steam is usually cheap and plentiful in steelworks, and its use helps to give the long and rather narrow flame that is necessary. The majority of the burners are made by the steelworks themselves and are of a simple type. It is interesting to note that very fine atomisation of the oil is not required for open-hearth furnaces. In fact, it is one application where really good atomisation would be a disadvantage, as it would not give the particular type of long, luminous flame required. The right type and design of burner has been fairly well established. The best design of furnace for oil firing has now to be found and, when this has been done, it is confidently expected that the present oil: coal parity of 1 : 2 will be considerably improved.

Oil as an auxiliary to steelworks gases.—Reference has been made to the practice of injecting liquid fuel into gas flames in order to give them luminosity and so increase the rate of heat transfer from flame to metal. This practice has been mainly confined to open-hearth steel furnaces, but it is suggested that it is one which might be extended to other furnaces in order to increase outputs and make better use of blast-furnace gas, or release coke-oven gas for other purposes. A few soaking pits and reheating furnaces have already been equipped for this method of dual firing, and results obtained to date indicate that increased rates of output are being obtained and that, even if only a small percentage of the total heat input is liquid fuel, the overall heat requirement is decreased.

A slab reheating furnace in Great Britain that has recently been equipped with dual firing is a continuous furnace, 80 ft. long × 20 ft. wide, from which outputs of 70 tons per hour have been obtained. The burners are arranged in three zones, the first zone (6 burners) being above the slabs, the second (6 burners) below the slabs and the final zone (8 burners) above the discharging doors. The first two zones, which, of course, supply the major portion of the heat input for heating the slabs, have been fitted with oil burners. The final zone, which is a soaking zone and, consequently, has a lighter load, has been left on mixed gas. The oil burners, which are of the steam-jet type, have been inserted through the gas burners and arranged so that oil can be burnt alone or with gas, or gas burnt alone. The results have been very satisfactory, the furnace being extremely flexible and no longer dependent on the availability of the gas supply.

It is suggested that, if this method was more widely adopted, coke-oven gas could be diverted to other uses for which a high calorific value, non-luminous gas is best suited. For example, if such gas was sold to public supply undertakings it would result in a useful saving of coal gas.

Rotary melting furnaces.—Although a number of these furnaces have been in use for many years, there is still a field for their increased use in foundries producing special irons, where three features are essential—(*a*) ability to superheat to a high temperature, (*b*) absence of carbon pick-up, (*c*) close control of composition. They would also be very suitable for those firms whose production of steel castings is not regular and who require a flexible furnace which can be used for either iron or steel castings at short notice.

The furnace is one that is completely rotated during the melt, by which means a large percentage of the heat is transferred to the charge by conduction from the hot face of the lining as it passes beneath the metal. This enables the furnace to be worked at an extremely high rating without high melting losses. Steel tubular recuperators are employed in view of the intermittent operation of the furnace ; all the air for combustion is preheated, air temperatures up to 450° C. being obtained. Table IX quotes approximate performance data given by the maker of a design of furnace that has now become almost standard. The figures are for melting iron, and tapping at 1450° C.

TABLE IX

APPROXIMATE DATA FOR OIL-FIRED ROTARY FURNACES

	(A)	(B)	(C)
Capacity of furnace . .	1 ton	2 ton	5 ton
Time for preheating from cold	40 min.	50 min.	60 min.
Melting time—first heat .	110 min.	140 min.	180 min.
Melting time—subsequent heats.	90 min.	110 min.	150 min.
Galls./ton iron, hot furnace .	33 galls.	27 galls.	22·5 galls.
Gross B.Th.U./ton iron, hot furnace.	58·5 therms	47·9 therms	40 therms
Overall space occupied by furnace, recuperator, etc.	16 ft. × 15 ft. 3 in.	18 ft. × 16 ft. 3 in.	22 ft. 9 in. × 23 ft.

The efficiencies of these furnaces can be considered reasonably high in view of the limitations imposed on the air preheat temperature by the type of recuperator that has, of necessity, to be used. The actual heat absorbed by the metal is as follows :—

Furnace A .. 49 per cent. of the maximum theoretically possible.
„ B .. 61 „ „ „ „ „ „
„ C .. 72 „ „ „ „ „ „

Interesting experiments to improve combustion efficiencies on one of these furnaces by means of interlinked air/oil control are now being carried out.

The rotary furnace when used for melting *special* irons and steels demands a uniform quality fuel, preferably ash-free, which is flexible and can be brought into use quickly. Moreover, the high working temperatures and rates of output needed demand a luminous, high temperature flame. All these demands are best met by oil firing.

Similar types of oil-fired rotary furnaces are used for melting and refining copper. An example of this use is a 10-ton capacity furnace which is melting a full charge in 65 to 85 minutes, the full cycle of melting and refining being about 4 hours. The furnace is averaging about 33 charges in a week of 135 hours. The oil consumption works out at 8 per cent. by weight of the metal melted, i.e. 1 ton of oil is used for 12½ tons of copper. This overall figure for fuel consumption cannot very well be expressed as an efficiency in view of the fact that the process has two distinct phases : the melting period when a high rate of heat input is required, and a longer period when a lower rate of heat input is required to maintain temperature during refining. Here again the demand for controllability and flexibility is admirably met by oil fuel.

Rotary calcining furnaces.—Liquid fuel is successfully used in long rotary furnaces of the cement kiln type where cleanliness of combustion is essential to avoid contamination of the material being heated. Such furnaces are often about 200 ft. long by 5 or 6 ft. diameter and are fired by a single oil burner along the axis of the drum or kiln, the products of combustion coming into direct contact with the material being treated. The combustion air is often preheated by the heat given up by the outgoing material. The actual oil consumption of a kiln of this type, with an output of just over 2½ tons per hour heated to 1,400° C., works out at 16 per cent. by weight of product heated. Results from two similar kilns, one oil fired and the other producer gas fired, show that one ton of oil does the work of just over two tons of producer coal.

FUEL ECONOMY[3, 7]

The first step in true fuel economy is to choose the right fuel for the job or—put in another way, which is particularly relevant when fuels are in short supply—to see that each fuel available is used for those jobs for which it is best suited. In this connection, it is not sufficient just to consider efficiency of use in the furnace in isolation ; the analysis must be carried right back to the original raw fuel in order to get a true picture from the broader, national standpoint.

It is hoped that this paper has demonstrated that one of the most appropriate fields for the application of fuel oil is high-temperature processes, where 1 ton of oil can very often do the work of 2 tons of coal. On the other hand, the general run of industrial boiler plants in this country, where 1 ton of oil will only do the work of about 1½ tons of coal, is not a profitable field for the use of oil, as on a thermal basis virtually no saving is obtained.

Where oil is used it is, of course, quite as important that fuel economy should be practised as where any other fuel is used, and various aspects of this question have been touched upon in this paper. Good design in the first instance is essential ; then, when the plant has been put into commission, fuel economy depends upon the correct operation and maintenance of the burner and air supply arrangements and upon the adoption of the many measures of heat conservation which are common to all fuels once their heat has been liberated in the furnace.

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2. Use of Oil in Open-Hearth Steel Furnaces

By W. F. CARTWRIGHT, M.I.MECH.E.

GENERAL

The main advantages of a fuel oil shop over a mixed gas or producer gas shop lie in increased production of the furnaces while working, lower B.Th.U. consumption per ton, and shorter repair times. The following are some points to which attention should be paid when converting an old shop or constructing a new one for burning fuel oil, if the advantages of doing so are to be fully obtained.

To make the most efficient use of oil fuel on an open-hearth furnace plant, attention must be paid to the detail layout of the plant. A plant specially designed and laid out for oil fuel burning should always improve on the performance of one modified from producer gas or mixed gas practice.

INCREASED PRODUCTION AND LOWER B.TH.U. CONSUMPTION

A properly designed and served fuel-oil furnace will have at least 10 per cent. faster production per working hour than the best producer gas furnace. In addition, there is the possibility of continuous working as no burning out of flues is required. When compared with furnaces working on bad producer coal the difference is much greater.

Comparisons between mixed gas and fuel oil are difficult, due to the wide variation in the luminosity of various coke-oven gases. But on high hot metal charges the fuel oil has a marked advantage due to absence of foaming. However, no producer gas or mixed gas furnaces have ever approached the production figures of the best furnaces on fuel oil in America.

Fuel consumption, with good producer practice, will seldom be lower than 7 million B.Th.U. per ton. Good mixed gas practice is about 5·5 million B.Th.U. per ton. Good fuel oil practice is 4·0–4·5 million B.Th.U. per ton. The fuel consumption on fuel oil is about half that on normal South Wales producer practice.

Too often the charging facilities both for hot metal and scrap of an open-hearth shop can only just compete with the performance when working on producer gas. A careful study must be made, therefore, before converting to fuel oil, to ensure that the charging time will not put a limit on production with the increased melting rates possible with fuel oil. The same arguments apply to teeming facilities which must be in excess of the output on oil to ensure that furnaces are never kept waiting.

As the viscosity of the oil supplied to the storage tanks is not necessarily constant, a continual watch must be kept so that the thermostat on the pre-heater for each furnace is re-set for every change. Perfect atomisation will only be obtained if the viscosity at the burner remains reasonably constant for a given burner setting. For the same reason, pressure pulsations must be eliminated ; with adequate air vessels this is quite possible even with reciprocating pumps, provided there are several units taking delivery of the oil.

In order to get the best possible combustion, and to avoid roof damage, elevation and vertical and horizontal angles of the burners must be adjustable ; and care must be taken by the operators that this angle is adjusted in accordance with any change in conditions.

The furnace should be specifically designed for fuel oil, as it is very wasteful to burn fuel oil in an out-of-date furnace with inefficient port ends. Obviously, adequate draught, combustion air and chequer volume must be available, but particular attention should be paid to the air uptakes and the spacing of the chequer work.

While the bugbear of burning out flues at week-ends necessary on all producer gas plants will be eliminated by the use of fuel oil, soot deposition in the chequers will still occur and therefore soot-blowing equipment must be provided, and the chequerwork arranged to take care of it. This equipment should both be at the side and underneath, the underneath blowers being used to blow back the soot dislodged by the side blowers so that it can be removed from man-holes provided for the purpose. This side soot-blowing necessitates leaving a large area of chequerwork uncased, and this expanse of brickwork should be sealed by spraying with an insulating compound.

With the tax on oil removed the fuel costs per ton of ingots will be about equal on fuel oil and producer gas, but the increased production represents a definite cost saving.

SHORTER REPAIR TIMES

A furnace designed to burn fuel oil only has port ends of a very simple construction, containing many less bricks than producer gas or mixed gas furnaces. The water cooling is also much simpler. There need only be two air uptakes, which should be of ample size, and these should be joined to form a bridge over the oil burner. The burner projecting between can then be kept very short, and should be entirely free of maintenance.

As there are no gas chequers, slag pockets should consist of one chamber only at each end of the furnace, access to the pocket should not be obstructed by casing or by a column. It is usually found when converting mixed-gas or producer-gas furnaces to oil that one of the main columns comes right opposite the centre of each slag pocket. This precludes the removal of the slag in one piece, which can be done in the case of a shop designed for oil with no obstructing columns.

The valve gear, being for air only, is of simple construction and will give but little trouble. It is, in fact, this simplicity which gives throughout the furnace a saving in repair time.

SULPHUR

Fuel oil with a sulphur content of up to 2·5 per cent. has been used in South Wales to produce a steel of 0·04 per cent. sulphur, but if a steel of 0·03 per cent. sulphur or less is required it is more difficult and may necessitate stipulating an oil of somewhat lower sulphur content.

3. Oil Firing in the Ferrous Metals Industry

By A. STIRLING, B.SC.

The extensive experience of my Company (Messrs. Stewarts & Lloyds, Ltd.) of various grades of oil for firing batch and continuous reheating furnaces calls for only two comments. We attach high importance to the regular and effective maintenance of the complete furnace system. Endorsing the author's remarks about oil burners, it may be added that the burner block is no less important for successful and trouble-free production.

A general description of an underfired heat-treatment furnace using creosote/pitch is appropriate to a conference on "Fuel and the Future". The process necessitated the accurate heat treatment, in the temperature range 600°–900° C., of alloy steel bars, mainly of the 1 per cent. Ni.-steel type. The stock varied from 2½ in.–7¾ in. in diameter and from 2 ft. 6 in. to 3 ft. 9 in. in length. Eight of the maximum-sized bars could be disposed on the 4 ft. 6 in. by 8 ft. 6 in. furnace hearth.

The combustion chamber having these dimensions and built throughout of first grade firebrick, was 2 ft. 0 in. high to the centre of the arch beneath the hearth and connected to the heating chamber through twelve vertical ports. The main ports (eight in number) were each 6 in. × 4½ in., while at each corner there was a smaller port 4 in. × 3 in. to ensure a sufficient supply of combustion gases to maintain a positive pressure near the doors giving access to the heating chamber. The heating chamber was constructed entirely of insulating firebrick. The combustion gases exhausted through four 9 in. × 6 in. chimney ports to a simple waste-heat recovery system. Temperature control was maintained with a Kent Multelec Mark II potentiometric two-point recorder linked to 10 S.W.G. chromel-alumel thermocouples in 1¼ in. o.d. ni-chrome sheaths.

In addition to the satisfactory performance of creosote/pitch as such, it was found possible to secure adequate heat treatment of the material with a mixture of this fuel and coke producer gas from a Government 5-therm producer (installed against a possible fuel oil shortage). It was the usual practice to raise the furnace to 610° C. in three hours using 6 gallons an hour of creosote/pitch. With practically the same thermal input, this temperature was reached in 3½ hours when 45 per cent. of the thermal input was producer gas and in 3¾ hours with 55 per cent. of the gaseous fuel.

4. Oil Fuel for Non-Ferrous Metals

By J. SYKES, F.I.M.

The main applications of fuel oil in the non-ferrous metals industry are as follows :—

(1) Copper smelting and refining.
(2) Reheating furnaces.
(3) Annealing furnaces.
(4) Light alloy smelting and refining.
(5) Brass casting.
(6) Zinc melting.

The use of liquid fuel in the firing of copper refining furnaces has the following advantages over solid fuels :—

(*a*) Uniformity of quality. This, of course, is vital to the metallurgical operation.

(*b*) Much cleaner than coal.

(*c*) Simpler to control and confers greater flexibility.

(*d*) No dust nuisance—generally gives a lower overall refractory cost and, due to there being no ash, only half the weight of slag is produced in the refining cycle, thus giving an appreciable reduction of metal loss.

(*e*) An appreciable saving in labour, there being no raw coal to store and no costly pulverising plant to maintain.

(*f*) It is much quicker to train furnacemen to fire with oil than with coal.

(*g*) The most important advantage is the saving of fuel. On a 175-ton capacity refining furnace, when using oil the average consumption was 40 therms per ton of throughput, whilst when using pulverised coal an average consumption of 50 therms per ton was obtained. No allowance is made for waste-heat recovery. This gives a ratio of 1 ton of oil to 1·7 tons of coal.

REHEATING FURNACES

Wire bar, cake and billet reheating furnaces are mainly oil-fired. Many of the advantages claimed for copper smelting and refining are also applicable to these furnaces, typical consumption figures being 5 to 6 gallons of oil per ton throughput.

ALUMINIUM REFINING

Oil fuel, due to its great flexibility and cleanliness, is the ideal fuel for aluminium refining and smelting.

BRASS CASTING

Oil-fired crucible melting furnaces here offer many advantages over solid fuel. The high calorific value and the ease of operation of oil fuel enables a close degree of temperature control to be maintained. The greater cleanliness of working due to the absence of ash and clinker leads to substantial economies, especially when melting the more expensive metals and alloys.

Oil firing also shows much greater efficiency than coke firing, giving lower overall fuel cost and greater output with higher furnace efficiency.

ZINC MELTING

Experiments carried out on a 50-ton zinc melting furnace have shown an overall thermal efficiency of 16 per cent. with coal but 25 per cent. efficiency with fuel oil.

FUEL COSTS

After taking due consideration of the advantages to be gained in the use of oil as a fuel, one very important point arises today. The reduction in the price of fuel oil as compared with the continually increasing cost of coal, causes the use of fuel oils to be more attractive to the industrialist.

5. Oil for Glass Melting

By E. J. C. BOWMAKER, M.B.E., B.SC., F.R.I.C., A.R.C.SC.

The previous authors are to be congratulated on a most comprehensive survey of the subject, so much so, that little is left for much further comment. I will, however, attempt to formulate some remarks as regards the impact of liquid fuel on such sections of the glass industry about which I am qualified to speak.

Whatever fuel is used for a particular process (and the selection of a fuel will depend on many factors) it should be used to the best advantage ; the technique necessary with different grades of liquid fuel will differ considerably.

As an illustration, during the War, I was concerned with the production of high-silica glasses (SiO_2 content approximately 81 per cent.) which were melted in furnaces of about 100 tons dead-weight capacity. Heat recovery by recuperators proved quite satisfactory using 200 seconds fuel oil, but it was found that creosote/pitch could not be used on this furnace because the large number of carbon specks produced by this fuel caused the glass to blister to a degree that rendered the manufactured products quite useless. The carbon apparently reacts with the arsenates present in arsenic refined glasses to form CO_2 bubbles which remain in the glass, particularly where its viscosity is as high as that of glasses of high silica content. This necessitated complete rebuilding of all the units to regenerative firing to ensure that carbon particles were not carried over to the working ends of the furnaces.

When the conversion was complete, an undertaking involving over two years' hard work, it was found that the radiation from the melting ends was insufficient to keep the working ends hot enough to manipulate the refined glass (with these glasses this temperature is of the order of 1420° C.) and auxiliary heating had to be supplied to this part of the units. Two hundred seconds oil was used for the purpose, with varying success with the normal burners available. For some time, good results were obtained only when this portion of the units were gas-fired. Eventually an Urquhart atomiser giving more perfect atomisation of the oil was tried with complete success.

An incidental outcome of the conversion was a saving in fuel due to the greater heat recovery of the regenerative system and to the use of high-pressure burners, with the consequent reduction of the percentage of unheated air.

One feature of the future use of oil in the glass industry, particularly with modern high-speed melting techniques, is the need for greater control of the amount of fuel fed to the burner. With regenerative-fired melting units, where sets of burners are in and out of use every 30 minutes or so, the temperature of the oil at the control valve varies considerably. Considerable fluctuation is also experienced with the usual controls employed in the branch heaters leading from the ring main to the burner. The temperature/viscosity charts given in the paper by Bailey, Battershill and Bressey show that quite considerable differences in viscosity can occur on account of these temperature fluctuations, thereby causing varying quantities of oil to be delivered to the burners.

The latest opinion, both here and in America, indicates that even the best possible control of oil temperature gives an inadequate burner control for modern melting methods. The only apparent answer is the use of metering pumps, i.e. positive pumps, with a variable speed attachment which delivers to each burner an exact and constant supply of oil under all conditions of oil temperature fluctuation likely to be met. I feel that metering pumps will become more and more widely used in the glass industry, as more exact temperature gradient control in the melting units becomes necessary to obtain the best rates of melting. This became evident when it was shown that by exact control of temperature gradient, greatly increased melting rates could be obtained for the same heat input. It may well be that variation in oil temperature at the burner is one reason why I have never been able to operate regenerative furnaces at so consistently low a figure for excess air as has been possible with regenerative furnaces fired by producer gas. Gas-fired regenerative units have been run consistently at 5 per cent. excess air but oil-fired regenerative units average much more nearly 10/12 per cent. excess air. This state of affairs does not apply to recuperative units using oil firing where the excess air can be easily controlled to quite low figures.

Many though the advantages are of oil firing in the glass industry, there are disadvantages. The chief of these is the intensely local effect of the flame causing a great increase in furnace wear both above and below the glass level. The life of furnaces is shortened and the repair bill increased by the use of oil. Nor can it be claimed successfully that the rate of output is better by the use of oil than, say, producer gas, notwithstanding the lower flame temperature of the gas.

It appears that the high radiation from oil flames can only be obtained by comparatively short hard flames and this limits the heat input to the melting unit. The experience of many glass technicians must be in line with my own, in that, although the limiting factor as regards heat input is the danger to small but vital parts of the refractories by the localised radiation of the oil flames, it would only seem possible to spread the advantage of the high flame temperatures obtained by oil flames by a cumbersome multiplicity of burners. This may account for the fact that the highest melting rates expressed in tons of glass melted per sq. ft. of melting area have been obtained, so far as I can ascertain, by gas-fired units where although the luminosity of the flame may be less it is much more dispersed in its effect. These remarks only apply to glass manufacture. The conditions attending steel manufacture, for example, are quite different and their experiences may, therefore, run to contrary conclusions.

The authors of the first paper have made some play with the fact that a certain weight of oil can give results achieved only by a greater weight of coal. Such statements in themselves have little meaning, and are not justified even in bolstering up such expedients as are fashionable now. Unfortunately also, the best fuel for the job can often not be used because the final determining factor is not as the authors state, that which gives the maximum output for the minimum overall expenditure of heat ; but that which gives the maximum output for the minimum expenditure of money ; and the terms are by no means synonymous. During the 1926 coal strike many glass-making concerns went over to oil firing in spite of the fact that the cost was higher. The difference in cost was endured as an insurance. But even when cheap creosote was available (i.e. when it bore no tax) up to 1939, the last year that the various fuels found their own price levels, coal firing by way of producer gas with its attendant additional costs was in the main the cheapest method of firing in the glass industry. (I am neglecting certain restricted areas where coke-oven gas was supplied at a by-product rate.) In support of this contention, I can instance one very large glass factory which undertook a conversion from fuel oil to producer gas as an economic proposition.

The ideal would appear to be a dual system designed to change from one to another as the market determined, and the proportion of the total cost of glass manufacture represented by actual fuel charges is such that a dual system may quite well pay for itself by taking full advantage of even small price differentials, besides adding to the insurance against failure of supply of one fuel or another.

6. Oil Firing on the Railways

By A. W. J. DYMOND, B.SC. (ENG.), A.M.I.C.E., A.M.I.MECH.E.*

As a contribution to the discussion on the subject of oil firing it would, I think, be not inappropriate to refer to the steps being taken by the railways of this country, at the request of the Ministry of Fuel and Power, to convert a proportion of the locomotives of the country to oil burning, thus releasing coal for other purposes. The target at which the conversion aims is the release of approximately one million tons of coal per annum, at present being burned in locomotives. This entails the conversion of 1,229 locomotives and the installation of 60 oil storage depots spread throughout the country.

Prior to this large-scale conversion, the Great Western Railway had converted ten of their large 2–8–0 freight engines to oil burning, had installed two storage installations in South Wales, and were proceeding to expand this programme to a number of their large 4–6–0 four-cylinder passenger engines, with addition of seven more storage depots. The experience of this company with oil burning on their own locomotives was so satisfactory that the large-scale conversion now being undertaken by all railway companies is based on Great Western Railway practice, which was designed in conjunction with the North British Loco Co., Ltd. and the Petroleum Board. In many of the details the Great Western design of the components is being adopted as standard for all engines.

The expected consumption of oil per day throughout the country by the railways when the conversion is completed will approximate to 2,500 tons and, in order to ensure adequate supplies always being available, storage capacity of approximately 43,000 tons is being installed. This represents a fourteen-day supply in tank capacity, which has been recommended by the Petroleum Board for safe stand-by.

This large-scale conversion of locomotives to oil burning is probably one of the most comprehensive changes in railway operation which has ever been undertaken by the railways of the country as a whole, and the fact that it is intended to carry the thing to its completion within a few months is entailing the use to the fullest extent of all the companies' resources, particularly on the technical and design side, both for the locomotive equipment and the storage installations.

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* Assistant to Chief Mechanical Engineer, Great Western Railway Co.

The Ministry of Supply is undertaking to supply to the railways or their contractors the whole of the equipment necessary both for the engines and the storage plants, and a start has already been made on the production of the vast quantities of material and detail components which are involved. The magnitude of the undertaking can be gauged from the fact that for every locomotive converted to the use of oil burning, one rail tank car of 3,000-gallons capacity will be kept in constant service to supply that locomotive with oil.

The equipment on the locomotive consists of a Weir burner situated under the tube-plate in the firebox of the engine, the oil being atomised by means of a steam jet. A new floor to the firebox is necessary and the bottom portion of the walls, as well as the floor of the box, is lined with special high-alumina refractory material. Each tender is to be fitted with a steam-heated oil fuel tank and provision is made for the connection of an auxiliary supply of steam to the locomotive for lighting up from cold.

At the storage installations, the problem of siting the large storage tanks and finding room for the necessary sidings for the reception of the rail tank cars simultaneously with the berthing of locomotives for the replenishment of the tanks, has necessitated the exercise of considerable ingenuity in siting the plant in a suitable position in the locomotive shed yard, so that the engines can proceed to their normal berthing points without undue dislocation of the usual method of working in the depots.

When an engine is converted to oil burning not only is a saving of coal effected but labour now necessary on each coal-burning locomotive for the cleaning of fires, de-ashing of ashpans, smokeboxes, etc., is eliminated, and the turn-round time of the locomotive at the depot can, subject to train services permitting, be reduced very considerably. On the road the engine is capable of maintaining the highest evaporation rates for lengthy periods, owing to the absence of the restrictions placed on the coal-burning locomotive by the dependence upon the physical effort of the fireman in lifting coal from the tender into the firebox, and by the complete removal of the deterioration of the fire owing to the aggregation of non-combustible matter in the coal choking the firebed. The fireman's duty with an oil-burning locomotive entails, however, close and intelligent co-operation with the driver's working of the engine.

Based upon Great Western Railway experience it can be said that the oil-burning locomotive, both on the road and in the shed, exhibits considerable advantages over the coal-burning engine. From the point of view of cost, of course, the balance is still against oil, but in the present stringent position for coal and the vital necessity for the railways to maintain public transport in operation despite all difficulties, the conversion to oil is rendered essential. It is, nevertheless, a matter of grave concern that the railways of this country must turn to the use of an imported fuel for their operation, even to the point of hauling trains of coal by locomotives fired with oil.

Discussion

Mr. Wheeler suggested that if any difficulties were found in getting an oil burner, a paint spray nozzle should be used.

Mr. G. Vivian Davies said that there was one point which was of great importance in the conversion to oil, and that was that in various industries a variety of different coals commonly had to be used. For example, one grade of coal was used for the initial firing, another grade to get up to maintenance temperature, and so on, and sometimes it was necessary to use three or four different grades of coal. The separation and segregation of those coals was not an easy matter. If those coals could be replaced by one fuel only a distinct advantage would be achieved. This was certainly operative in some branches of the ceramic industry though not in others.

Mr. Gollin said that it was very useful to have had in the course of that discussion a short résumé on the application of oil fuel to locomotives. The application of oil for this purpose, bearing in mind that here was a combustion chamber built essentially around a rectangular grate and not evolved for the use of liquid fuel, had emphasised the arguments put forward by the authors of the paper. It was evident, that owing to ease of control, it might be possible to have coal-fired locomotives converted to oil fuel to enable one therm of oil to do the work of 1·1 or 1·2 therms of solid fuel. He had no figures which indicated a very much higher thermal ratio. In this conversion programme the railways were going to burn thousands of tons of oil. The authors of the paper had indicated, however, that if the application were chosen carefully it should be possible not only to save weight of fuel (that did not matter at all) but, what was more important in the national interest, to make one therm with liquid fuel do more than was done before with one therm of solid fuel.

One speaker had advised the use of the paint spray if there was difficulty in getting an oil burner. Many of the early oil burners were designed to operate on the paint spray principle. This, however, had two defects. First of all, with every pound of oil burned, one used about 15–18 lb. of air. An oil burner, therefore, should be chosen that was economical of air. That was very important. One had to bring in the air at the right velocity and mix it thoroughly with the fuel ; it was not only the atomising of the oil that counted. Secondly, the paint spray might not atomise to the degree of fineness required for combustion or to the degree of uniformity which was necessary. It was desirable as far as possible to avoid getting some big and some small drops. Uniformity was to be sought, and for this reason the burner should be able to deliver a fine atmosphere of even-sized particles.

Professor Leslie Aitchison referred to remarks made by him at sessions of the conference on the use of oil fuel in the non-ferrous industries, particularly the copper and brass trades. To these industries oil firing possessed certain attractions that made it popular. Apart from the psychological advantages of knowing and controlling one's fuel supplies, there were certain technical advantages. In the first place the operator was relieved of any trouble in respect of the removal of ashes. Secondly, oil fuel tended to operational economy as it was very easy to turn off the tap when the heat was not required. Thirdly, oil firing had an advantage over many other forms of heating in that it was possible to add heat rapidly when one wanted to. This flexibility was valuable.

Furnace installations to use oil fuel, because of their simplicity, could be relatively small in dimensions and also relatively cheap. Furthermore, maintenance was a reasonably straightforward matter provided the furnaces were suitably designed. He therefore desired to endorse what other speakers had said and to stress the importance of designing furnaces specially for use with oil fuel. Those furnaces he had seen where the consumption had been lowest and the throughput highest, were furnaces of the in-flame type, designed with particular care to ensure that the heat generated at the burners impinged directly on to the metal. By making the furnaces snug there was less chance of the flames escaping contact with the metal, and consequently smaller loss of useful heat into the stack.

In the fabrication of light alloys the problem was a little more difficult, as it was not reasonable to expose light alloys to direct contact with the flames. This involved the designing of suitable muffle furnaces to operate at temperatures round about 500° C., and he felt this problem had not yet been adequately tackled. There was ample room for co-operation between the fuel oil expert and the furnace builder to produce something which would be economical in fuel, convenient to operate and, at the same time, would not entail excessive maintenance of the furnace by reason of uncontrolled impact of the flames on the refractories.

From cost figures relating to the non-ferrous industry for the year 1944, it seemed to him that oil was overtaking coal, even at that date. For what they were worth, the figures showed that the cost of reheating brass with coal firing was 6*s*. 6*d*. per unit and only 7*s*. 3*d*. if fuel oil was employed. When melting brass the most favourable conditions were those found in the low frequency induction electric furnace. On the 1944 figures which he gave, again for what they were worth, the relative costs were 13*s*. per ton for low-frequency electric heating, 16*s*. 9*d*. for coal firing, and 20*s*. for fuel oil. Possibly these figures had come closer together during the last two years.

Mr. T. C. Bailey, replying as one of the authors of the original paper, said how glad they had been to have Mr. Cartwright's contribution on the efficient use of oil firing in open-hearth steel furnaces. Mr. Cartwright had described one of the few really new developments in oil firing established in recent years, and it was an application where all the advantages of oil could be used to the fullest extent. He and his co-authors were also very glad to have such an authoritative statement that the repairs to the furnaces could be carried out in a much shorter time than on a gas-fired furnace. This should be reassuring to those people who were converting to oil firing.

One point made with which he was in entire agreement was that the furnace should be specifically designed for oil firing in order to get the best results. This recommendation applied to all applications of oil firing, and in this connection he rather disagreed with Mr. Bowmaker's suggestion that furnaces should be laid out so as to use either oil or gas, whichever happened to be cheaper at the time.

Mr. Bowmaker had told them the disadvantages of oil. He wondered whether his experience had been due to his method of the application of oil, because many glassworks were securing higher rates of output with oil than was normal with gas firing, and the furnace life had not suffered. Furnace life should be quoted in terms of output rather than in terms of time.

Returning to the question of designing furnaces for oil and not trying to convert a gas-fired furnace for that purpose, Mr. Bailey said that the glass designers knew that port design and the position of the burner were points that needed very careful consideration, and he wondered whether the experience of the steel industry in this connection might not be helpful to designers of glass furnaces.

Mr. J. W. Oliver wrote : In the application of oil burning to open-hearth furnaces, no mention is made of mechanical atomisation, i.e., high pressure atomisation without the aid of steam or air. The technical press gives no indication of its being attempted in this country or America, and in view of the advantages it brings, such as simplification of plant, cost, and high mass velocity, it should be considered.

It may be found practicable to reduce the cost of preheating fuel oil by making the burner housing an integral part of the flow circuit, thereby cooling this part of the plant. Carbonisation could be prevented by retaining water-cooling to a certain extent and flow variation with furnace load could be taken up by retaining the heating apparatus which normally handles the major portion of the flow.

Centralised control should be encouraged, particularly when fuel oil is applied to the iron and steel industry.

Mr. C. H. Williams wrote : Having experience in the use of oil on medium and the very largest furnaces, I can support most of the claims made for oil. It was emphasised and rightly so, that oil-firing systems must be well engineered with the fullest provisions for cleanliness, filtration, and constant pressure and temperature of re-circulation. The oil burning equipment now available in Great Britain is of a very high order, not only in respect of the burners but also of the means for control including the highly important automatic control of combustion.

Certain comparisons were made with coal or producer-gas firing. Here I must mention that one particular advantage claimed for oil, i.e. that heat can be applied to the furnaces without the periodical shut-downs said to be necessary with producer gas is more apparent than real.

It is not generally realised that in the glass industry a number of works use raw producer gas carried in gas mains so designed that weekly shut-downs are dispensed with, and gas is supplied at the correct rate and pressure not only over weeks or months, but over years of continuous operation. Coupled with gas main design in achieving such results is the use of steam sootblowers and lances periodically manipulated by trained operators during actual gas supply.

The Chairman of the Section, **Dr. R. J. Sarjant,** summarised the principal conclusions as follows : The main suggestion arising from this session was the need for what was aptly described as good housekeeping, constant vigilance and the realisation that such existing plant does not come up to the standards which are attainable.

The short-term policy required may be summarised as follows : attention to the planning of plant and loading, and more investigation of the fluctuations arising from market requirements ; a proper recording and sifting of data, which should be assisted by systematic, planned surveys by experts ; rigid plant and process control ; teamwork and understanding between management, technical staff and operatives ; and a reduction of the hard core of prejudice against new ideas.

The long-term policy calls for more application of the available results of research and of existing knowledge and skill and the field of investigation is more than ever the works as well as the laboratory. Proper co-ordination of research by the right people also requires further consideration. It has many applications, and a fundamental and scientific approach to the problem can be the only means of further economy.

Thus, in major producing units, like those making iron and steel, glass and non-ferrous metals, there is need for the production of improved refractories, particularly for hot-face insulation and for resisting high-temperature erosion ; in gas producers the use of preheated blast to improve the quality of the gas ; possible use of higher pressures in gas condensation and more automatic control ; sizing studies for fuel and the other widespread developments which would follow on the discovery of a cheap method of producing oxygen.

Immediate and serious research was called for in this last category, and it would have outstanding results. The use of oxygen opens immense possibilities for those large users of fuel such as the blast furnaces, all types of smelting furnaces and the gas generator.

In the design of plant, the need for mechanisation and the proper selection and placing of controls was emphasised. Further economies might result from a greater application of heat recovery, particularly in the form of a recuperator, which is capable of wide application. More flexible mechanical stokers are looked for in furnace practice.

Oil fuel is appropriate for high-temperature processes where one ton of oil can often do the work of two tons of coal. Good design is essential in the first instance, and subsequent economy depends upon the correct operation and maintenance of heating services, as with other fuels.

In quite a number of directions, as explained in detail in the papers and discussions, there is considerable scope and opportunity for improvement.

SECTION E

THE CARBONISATION AND CHEMICAL INDUSTRIES

Chairman: Dr. E. V. EVANS, O.B.E.
MEMBER OF THE FUEL EFFICIENCY COMMITTEE,
MANAGING DIRECTOR, SOUTH METROPOLITAN GAS CO.

SESSION I. The Gas Industry

Chairman of Session: DR. E. V. EVANS

THE CHAIRMAN called attention to the many purposes for which fuel was needed at a time when coal was short in supply. The task of supplying the additional coal required and of keeping fuel costs at a reasonable level would appear impossible but for the fact that a very large part of the coal consumed in the past had been wasted. Sufficient savings could be made to enable fuel demands to be met by current production. The savings so far achieved by the fuel efficiency campaign, although so helpful in the present urgent need, were small in comparison with the further 20 million tons a year which was the target. The three industrial groups linked in this section were closely linked because two depended on the process of coal carbonisation—a method of chemical processing—whilst many of the products of coal carbonisation formed the basis of operations in the chemical industry. The unit processes of chemical engineering were in common use in these three industries.

1. The History and Work of the Regional Gas Engineering Advisory Boards

(*Three papers were presented dealing with this subject*)

(i) The Efficiency of Carbonisation and the Work of the Regional Gas Engineering Advisory Boards

By S. E. WHITEHEAD, B.SC., M.I.C.E., M.INST.GAS.E.
CHAIRMAN, CO-ORDINATING COMMITEE OF REGIONAL GAS ENGINEERING ADVISORY BOARDS, THE INSTITUTION OF GAS ENGINEERS.

Carbonisation is the most efficient known method of processing coal.

The thermal efficiency of the carbonising process, as carried out in modern gasworks and coke-oven plant, is of the order of 80 per cent. In saying that I realise that I have "grasped the nettle", for I know there are some here who will dispute the statement, or at any rate the method of calculation it implies. My reason for introducing a controversial note at the outset is the fact that this "Overall Thermal Efficiency" is the means we have adopted, and are still adopting, to measure the performance of gasworks plant in our endeavours to increase efficiency and so to save coal.

The results of carbonising one ton (300 therms) of coal in modern plant working under good conditions may be taken as :—

	Potential therms	Percentage on coal
Gas (75 therms)	75	25
Coke (10 cwt.)	140	46·6
Tar (11 gall.)	20	6·7
Benzole (3 gall.) . . .	5	1·7
	240	80·0*

This means that in good carbonising practice 80 units of heat are rendered available for use out of every 100 units consumed in the form of coal. If overall efficiency means the proportion of the original heat rendered available for useful work—and I suggest it cannot mean anything else—then it is clear that the overall thermal efficiency of the process is 80 per cent.

Conversely, the heat expended (and lost) in operating the process is 20 per cent. and this is the figure (the " Fuel Expenditure Index " or F.E.I.) which was originally suggested by the Ministry, and which we have used in practice with very satisfactory results.

Inevitably, certain criticisms have been directed towards this practice, the principal one being that a more scientific basis of assessment is a formula recently put forward by Dr. Pexton which gives a figure known as the " Efficiency of Gas Production ". This assumes that the coke remaining from the process is of the same thermal value as the original coal and that the fuel expenditure is therefore reduced by that amount. The efficiency of gas production is therefore expressed as

$$\frac{\text{therms in gas} \times 100}{\text{therms in coal} - \text{therms in coke for sale} - \text{therms in tar, etc.}}$$

A simpler form is $\dfrac{\text{therms in gas} \times 100}{\text{therms in gas} + \text{therms in producer fuel} + \text{therms lost}}$

This may be, and probably is, a more technically correct method of assessing the efficiency of production of coal gas only, and is undoubtedly of great use in comparing the gas-making efficiencies of different types of plant in that it debits the whole of the fuel consumed to the one item, gas. We, however, are concerned with coal saving and, therefore, with the whole gasworks process, and we contend that for our purpose it is more logical to debit the fuel consumed to all the useful products, as is done by the use of the F.E.I. formula.

In this connection, it is interesting to refer to the report presented to the Institution of Gas Engineers in 1919 by Sir Dugald Clerk, Professor Smithells and Professor Cobb. They worked out the "Thermal Efficiency of Carbonising Gas Coal " in the case of two typical undertakings in exactly the same manner as we are doing, and stated that, at that time, " the heat used for carrying out all the operations of gas manufacture amounts to 20 to 29 per cent. of the original heat of the coal treated ". They proceeded to discuss how this heat loss should be distributed, and expressed the view that a strictly scientific procedure required it to be distributed "*pro rata* among all the combustible products, if we regard it as purely a thermal problem ". They added, however, that as they were under strict injunctions to present the most conservative estimate, they had " with reluctance " adopted a formula which was, in effect, the Pexton formula and in which the whole fuel loss was debited to the gas.

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* These figures refer to horizontal retorts. Some processes, *e.g.* steamed vertical retorts may give a higher efficiency and different proportions.

We contend that ours is " purely a thermal problem " and that the use of the F.E.I. formula is justified by the above report ; and it is interesting to know that our method has been adopted by Mr. Heyworth's Committee of Enquiry into the Gas Industry, by the Egerton Committee, and by Sir Ernest Simon's Fuel and Power Council.

ORIGIN AND DEVELOPMENT OF BOARDS

At an early stage of the war it was recognised that, owing to the tremendous increase in the demand for gas for munitions industries, some of the smaller undertakings in the Midlands would experience severe difficulties in meeting their obligations.

By mutual consent and by the public-spirited enterprise of the Midland Association of Gas Engineers and Managers, an Investigation Panel was set up for the purpose of inspection and consultation in such cases, and the provision of advice and material assistance to embarrassed undertakings. A complete survey was made of all undertakings in the Region and, without going into details, it may be said that the Panel, with the willing co-operation of all concerned, performed most useful work which in its results proved of vital importance to the war effort.

It will be clear that the efficiency of the carbonising process loomed very largely in the panel's considerations and accordingly, when the Ministry found it necessary in 1942 to appeal to the gas and other industries to do their utmost in the direction of coal conservation, similar panels known as Gas Engineering Advisory Boards were set up in all Regions. The boards were under the aegis of the Institution of Gas Engineers and were modelled closely on the Midland Panel, whilst their activities were and are still co-ordinated by a Committee consisting of the chairmen and honorary secretaries of all boards, together with the General Purposes Committee of the Institution.

The members of the boards are selected from works of all sizes spread as equally as possible over the Region, and their function is to visit undertakings in their neighbourhood, to discuss and advise upon problems bearing on efficiency and to follow up the completion of questionnaires which are issued and collated by an executive committee of the Region. Their visits have frequently been followed by assistance, the supply of materials and plant, and the loan of technical personnel.

For some years a quarterly, and more recently a half-yearly, report was forwarded to the Institution, giving tabulated F.E.I. figures for all undertakings, and general information regarding conditions in the Region. In this connection it should be stressed that the F.E.I. figures have never been used for the purpose of comparing one works with another, but only for ensuring that the standard of operation at a particular works is maintained or, if possible, improved.

In general, the effect has been most satisfactory. The visits and questionnaires have been received in an admirable spirit of co-operation, and the contacts and discussions have been found to be of mutual advantage to the engineers concerned, whilst the returns have covered up to 95 per cent. of the coal carbonised.

There have, of course, been difficulties and it may be admitted at once that thermal efficiency was something rather new to some of the undertakings. A larger number were unable to guarantee the accuracy of their returns, particularly with regard to the weighing and measuring of large quantities of materials. Some of these difficulties indeed were experienced in practically all undertakings and were, as can be easily understood, directly due to wartime conditions, resulting from the absence of facilities, acute shortage of technical staff, and consequent difficulties in control of plant and sampling and analysis of materials.

Another difficulty which has been experienced was due to the differing types of plant and methods of operation in use in various works, and this was particularly evident with regard to water-gas manufacture.

The thermal efficiency of water-gas production is lower than that of the carbonisation of coal, and varies with the degree of enrichment, *i.e.* with the quantity of gas oil used. Where, for instance, " blue " water gas (*i.e.* water gas with no oil enrichment) is produced at a calorific value of about 290 B.Th.U. per cu. ft. with a thermal efficiency of 60 per cent. a carburetted water gas of 470 B.Th.U. gives an efficiency of 70 per cent., and one of 560 B.Th.U. of 75 per cent. It will therefore be appreciated that the inclusion of water gas in varying proportions between one period and another had the effect of making comparisons difficult, whilst such variations in both quantity and quality of water gas became more pronounced in consequence of the shortage of coal and labour, air-raid damage, and other war conditions. In fact the position was aggravated by the Ministry's recent appeal to all undertakings to make the maximum practicable quantity of water gas, *i.e.* to use carburetted water-gas installations as base-load rather than peak-load plant.

In consequence of this difficulty the F.E.I. of coal gas production at each works has been tabulated separately in addition to the overall F.E.I. of the works, and the former figure has been used in reference to our coal-saving campaign.

RESULTS OBTAINED

It is the view of the co-ordinating committee, and I believe also of the Ministry of Fuel and Power, that the efficiencies of gas manufacture throughout the country have been maintained through a very difficult period to a surprising degree. Whilst the general tuning-up of plant and striving to excel have brought about a small increase in average thermal efficiency, no-one would have been surprised if the results had shown a progressive falling off over the past five years. To the shortage of labour, the impossibility of maintaining plant, and the increased demand for gas, must be added not only a steady deterioration in the quality of coal carbonised, but the extreme variability of coals supplied, and the carbonisation of many coals which would never before have been accepted for the purpose.

The results obtained throughout the past five years have been steady and most satisfactory as indicated by the weighted averages of the returns. For the December half of 1944, for example, the F.E.I. figure for 93 per cent. of the coal carbonised in gasworks in Great Britain was 23·9, or a thermal efficiency of 76·1 per cent. Most of the works from which returns were not obtained were in Scotland, and, with these excluded, the F.E.I. for 8,854,000 tons of coal (98 per cent. of the whole) was 23·6.

The corresponding figure for the whole of 1945 was an F.E.I. of 23·8 (76·2 per cent. efficiency).

Whilst these results compare very favourably with the 80 per cent. which I mentioned earlier, it is of the utmost importance to remember that the latter figure refers to the carbonising process only, whereas the F.E.I. returns cover the whole manufacturing plant, and include such ancillary matters as power required for handling of materials, steam for driving exhausters and pumps, etc.

For the purpose of collation the F.E.I. returns were grouped into :—Under 25·0, 25·1 to 30·0, 30·1 to 35·0, and so on ; and it is of interest to note that figures taken out for 1944 show that 72 per cent. of the coal was treated with an efficiency in the highest class, i.e., over 75 per cent. The weighted average for that 72 per cent. was an F.E.I. of 20·8, or an efficiency of 79·2 per cent.

A further interesting study has been the comparison of war-time efficiencies with those of 1938–39. In the undertakings for which figures in both periods were available, the F.E.I. relating to 6,400,000 tons of coal in 1944 had increased only to 20·6 from the figure of 19·95 in the pre-war years.

THE FUTURE

The maintenance of gasworks efficiency under the adverse conditions of a long war represents a substantial saving of coal when compared with the falling-off which might reasonably have been expected, and there is no doubt that this is largely due to the splendid team work and co-operation which have existed between gas engineers generally and the Regional Gas Engineering Advisory Boards. If we can effect such a saving under those conditions, how much more might we save in the more normal conditions which are now slowly but surely returning. This thought has led us to decide that the boards' activities shall continue.

Without doubt, there is much scope for further economies of fuel in gasworks. The principal fields are two :—One concerns improvements in design, particularly in regard to producers, recuperators and the insulation of retort settings, and this is largely the function of the plant designers and builders. The other is the responsibility of the technical personnel of the industry in ensuring that fuel-consuming plant of all kinds is maintained in good condition and operated in the most economical manner possible, for without skilled supervision waste will occur in plant of the most excellent design. As a corollary it is important that more properly trained technical men should be employed within the industry.

Apart from these main items, however, much fuel can be saved (especially when more normal conditions obtain) in such matters as the use of exhaust steam for process work, the lagging of steam pipes, attention to the load factor of ancillary machinery, etc.

Finally, one of the greatest needs of the gas industry is to be supplied with ample coal of good quality and low ash content, for that would result in enormous savings in fuel, transport and labour.

(ii) The Importance of the Effect of the Correct Allocation of Coal on the Future Efficiency of Coal Utilisation

By NORMAN HUDSON, M.INST.GAS E., M.INST.F.

Design and planning of fuel utilisation for the future cannot be achieved unless those in control of supplies will accept constructive advice from those who have specialised knowledge and experience of fuel matters.

The achievement of the objective of making every ton of coal do as much work as possible is hampered by the apparent absence of any serious attempt to allocate the available coal supplies to their proper purposes. In the gas industry, when coal and plant is in short supply, the measure of useful work done by a ton of coal is surely the measure of the number of gaseous therms that it will produce. The casual, as opposed to the considered, allocation of coal, as such, to the gas industry, can more than off-set all the advantage achieved from the detailed endeavours that are made in the works and on the district to achieve a high efficiency in gas production and utilisation. For example, a gas undertaking whose coal supplies are changed so that the gaseous therms made per ton are reduced by 10 per cent. would require 11 per cent. more coal by weight to meet a given gas demand by the public, and would have to use 11 per cent. more plant, with all its attendant increases in the use of furnace fuel.

It is not true that the gas and coke-oven industries are today getting all the coal mined in this country which is suitable for carbonisation and that there is not sufficient of that coal to meet their requirements, so making it necessary for them to take less suitable coals more ideally suited to steam raising. An appreciable tonnage of coal of good gas-making properties is today being directed to industry and the domestic grate to be burned in its raw state, and certain coal more suitable for industry and the domestic grate is being directed to the gas industry. The result is that there is a loss of efficiency all round. In the gas industry, more plant, more man-hours, more maintenance and repairs and a bigger weight of coal are being required to produce a gaseous therm than is necessary. One very large undertaking in Yorkshire today is using 14 per cent. more plant and labour for a given output of gas than it was using immediately before the war, due to one fact alone—namely, that their best quality gas coals have been reduced in supplies and that substituted has been much inferior from a gas-making point of view. Can we afford to let this continue ? Is it consistent to call for detailed economy in the use of fuel and neglect one salient point, attention to which may contribute handsomely to the objective in mind ?

Those who are responsible for the allocation of coal should seek advice from those who understand coal values. The Gas Engineering Advisory Boards would be very willing to place the knowledge they have available at the disposal of those responsible for the allocation of coal. Nothing short of a complete analysis of the coals available will do, this to be followed by a re-direction of all coal which has been wrongly allocated. To give to the carbonising industries full priority for all coals mined in this country that are suitable for carbonisation would impose no hardship on any other industry and would contribute materially to an improvement in the present coal position and in the more efficient future use of the national coal supplies because it would cause (i) a reduced tonnage demand for coal by the carbonising industries and (ii) a higher yield of good quality coke.

(iii) The Efficiency of Carbonisation and the work of the Regional Gas Engineering Advisory Boards

By C. F. W. RENDLE, O.B.E., M.INST.GAS E., M.INST.F.

One factor which led to the formation of the original Midland Panel was the great increase in the demand for town gas in the early part of the war, and the fact that owing to the migration and dispersal of industrial plants this increased demand was frequently made upon gas undertakings in rural or erstwhile purely residential areas, whose previous experience had not equipped them to deal with such unusual conditions. The wartime load was invariably in the form of a continuous 24-hour demand with little if any seasonal fluctuation. These undertakings were thus provided with no interval for the customary overhaul and repair of plant which was for the most part wholly in constant use. This feature more than any other led to the necessity for some collective action in the Midlands, and, as Mr. Whitehead has stated, the enterprise known then as the Midland Consultative Emergency Panel was formed.

The technique employed in our attack upon the immediate problem of avoiding breakdown of gas supply to the munitions industries was nothing more than the logical application of fundamentally sound and well-established principles and provision of technical (and often manual) assistance where it was needed. Often the problem could not be dissociated from production efficiency. Apparent shortage of labour or inadequacy of plant would be found upon investigation to be caused by poor process efficiency. The Board of Trade, Directorate of Gas Supply, and Dr. E. W. Smith personally as Director-General, encouraged our work and it was largely Dr. Smith's inspiring enthusiasm which fostered our development. There was given us wholesale co-operation by the gas engineers concerned and it soon became evident from statistical information from fourscore undertakings in our area that a wide field existed for the expansion of our work.

These modest efforts preceded the devising of the much debated formula (by Dr. Smith and his staff) for the assessment of carbonising efficiency by Fuel Expenditure Index. When the merit of this or any other formula is discussed it should be remembered that as long as the gas industry is a " two-fuel " industry, the efficiency of carbonising must be a more appropriate index of its usefulness than the efficiency of gasmaking.

While the credit is not claimed wholly for the Gas Engineering Advisory Boards, the incentive provided by their work was largely responsible for the remarkable result described by Mr. Whitehead. No organisation other than the advisory boards exists to perform this work. Moreover, it is clear from the nature of the work that no alternative body whose structure differed materially from that of the boards could successfully undertake it under existing conditions, for local knowledge of methods and circumstances must be applied to the proper interpretation of the statistics. Among the principal factors are:—

(1) The wide variation in use of fuel as between one undertaking and another for process work, working up of by-products, etc.

(2) The variation in type and source of power employed for prime movers.

(3) The method employed for the computation of the gas volumes used in the assessment of the F.E.I.

The work of the boards in wartime is still of interest in retrospect, but it is the lessons which it taught and the deduction which the subsequent experience of all the Gas Engineering Advisory Boards have made possible which are of the greatest import to us now, and in the future. I can give only my personal views on the future work of the Boards:—

(i) While it is very difficult to be precise in the absence of a knowledge of what changes may be incidental to proposed nationalisation, there is common ground for agreement with the necessity for the integration of the industry resulting in the establishment of a smaller number of production and distribution units so disposed and of such a size as to provide processed fuels to the public with the best standards of service and at the lowest cost. This implies the use of the highest efficiencies practicable in production and distribution. Integration would result in some elevation of this collective efficiency.

(ii) The continuity of gas-making processes demands the constant exercise of watchful diligence in technical control.

(iii) Technical control must be extensively developed.

Whilst in theory there should be little difference in process efficiency between large and small carbonising plants of similar type, unless competent staff provided with adequate equipment is available, good results can only be achieved by trial and elimination. Small undertakings cannot afford the necessary staff and facilities. Of over 1,000 gas undertakings in the country, half produce less than 100 million cu. ft. of gas a year each. Integration would enable staffs to be available to these works to pursue higher processing and overall efficiencies. The collective effect would not be striking, of course, since these small works use only 5–6 per cent. of the total coal carbonised by the industry. The larger gas undertakings are magnificently equipped with technical resources both in staff and equipment of the highest order, and the existing high efficiency of coal processing in the gas industry is largely due to their work and the example which they have set. It is recognised, moreover, that these large undertakings are responsible for carbonising the bulk of the industry's total input of coal.

The qualifications of gas works technical staff are fundamentally those of a chemical engineer. The University of Leeds has for long done much training of men for the gas industry and the value of its work is acknowledged. I would refer also to the excellent movement inspired by Mr. T. F. E. Rhead, of Birmingham, in the establishment of a committee of representatives of the gas and allied industries in the Midlands in collaboration with the University of Birmingham, having the aim of providing facilities for this training and for the reception into those industries of such successful graduates as are necessary for their technically efficient operation. It is hoped that this committee may form the nucleus of a consultative body of manufacturers and industrialists in collaboration with the University on this matter of mutual interest.

The value should be emphasised of extending to the smaller units the practice, well established in larger works, of regular conferences of departmental technical staffs with the objects of co-ordinating their work, of avoiding the isolation of mere specialisation, and of interchange of opinion based upon experience.

2. The Application of Complete Gasification in Future Gas Making Processes

(Three papers were included under this title which are given here under the names of the authors)

(i) J. G. KING, O.B.E., D.SC., PH.D., F.R.I.C.

DIRECTOR, THE GAS RESEARCH BOARD

There is much positive evidence of the increasing demand for coal gas for industrial purposes. It has been shown that in seven typical industrial areas, the proportion of gas sold to industry had in 1943 reached 33 per cent. of the total gas produced. The return of peacetime conditions may have temporarily reduced industrial consumption, but undoubtedly a realisation of the advantages of gas in providing greater control of process work, and in high thermal efficiency of use will soon lead to a demand which will exceed wartime consumption. One industrial area already shows a remarkable increase from 30 per cent. in 1939 to 78 per cent. in 1946.

That this increased industrial consumption of gas is a desirable development from a national point of view is clear from considerations of the higher efficiency of use of the heat units in the coal consumed in the manufacture of gas. At present, however, the gas industry is a two-fuel industry, providing both gas and coke, and if the industrial demand for gas continues to increase, the industry must give serious thought to developing a method of manufacture which will provide more gas and maintain a suitable balance of sale of gas and coke. The balance could, of course, be maintained, using present methods, by a corresponding increase in sales of coke, and a much greater market for coke is, in fact, visualised in the Simon Report on Domestic Fuel Policy, in order to increase the proportion of smokeless fuel in the total of domestic solid fuel. Gas, however, could equally well meet the demand made in this report for a reduction in atmospheric pollution. However satisfactory solid fuel is in many ways, it is unavoidably less convenient than gas in requiring transport and storage, and in involving labour costs at the point of use.

Should it be accepted that gas can indeed replace solid smokeless fuel, to the national advantage, the obvious course for the future is the gradual introduction of a process of complete gasification, in which solid fuel is not produced, but whose by-products, if any, are marketable. Such a process would be chosen to suit British coals and conditions, and must provide gas at an economic price for all purposes.

Complete gasification processes have been advocated from time to time, but with one exception they have not been applied to a measurable extent, because the gas produced had the disadvantage of a low calorific value of the order of 250 B.Th.U. per cu. ft., so that its distribution and use would have introduced serious problems. The exception is the process of manufacture of carburetted water-gas which, when combined with the carbonisation of coal in the approximate ratio of 1 to 1·1 in gaseous therms at a calorific value of 480 B.Th.U., does form such a process, leaving only 8 per cent. of the thermal value of the coal as coke breeze. While the gas industry remains a two-fuel industry, the use of carburetted water gas as an auxiliary to carbonisation provides a valuable method of balancing the production of gas and coke, although it must be borne in mind that it consumes non-indigenous oil for carburetting. It is, however, an established process of gas manufacture, by which in 1939 some 10 per cent. of the country's gas was produced, but its main function has become that of meeting peak loads, its wider application as a base-load source of supply having been limited by a slightly higher cost of production and, to a lesser extent, by the high specific gravity of the gas.

Better prospects for a complete gasification process suitable for British conditions emerged with the application of the use of oxygen for the gasification of brown coal in Germany, and particularly with the use of oxygen under pressure. The importance of the latter is that methane is synthesised, and the resultant gas after purification has a calorific value approximating to that of British town gas.

The Lurgi pressure process of gasification has reached the stage of industrial application in two plants at Bohlen and Brux, the unit generator having an internal diameter of 8·2 ft. and a rated output of 2·5 million cu. ft. per day. With a reactive material like German brown coal, the percentage of methane in the washed gas reaches approximately 22 per cent. at a pressure of 21 atm., when consuming 15 cu. ft. of oxygen and 8 lb. of steam per 100 cu. ft. of gas made. The yield of gas is 24,400 cu. ft. or 112 therms, at a calorific value of 460 B.Th.U. The crude gas contains up to 30 per cent. of carbon dioxide and all the volatile sulphur compounds are in the form of hydrogen sulphide. Both are washed out by water under pressure and the clean gas is delivered at 20 atm. pressure to the distribution centre. A feature of the process is the requirement of oxygen, which is met by Linde-Frankl air-liquefaction units of appropriate size.

It was obviously of importance to the British gas industry to determine whether pressure gasification with oxygen could be applied with British coals, and a start was made in 1937 by the Joint Research Committee to study the reactions of the process. Those in the lower part of the generator, i.e. the action of steam and oxygen on coke under pressure, were studied by exploring the effect of variation of the steam : oxygen ratio between the wide limits of 3 and 13. Data were obtained regarding the probable composition of the gas in the upper zone of the generator, and studies were then made of the reactions of such gas mixtures, and of pure hydrogen, on coal and coke. The remarkable observation was made at this stage that hydrogen reacted with semi-coke at a high rate to give methane, not only by hydrogenation of the volatile matter, but also by direct action with carbon. In fact, at a sustained temperature of 800° C., up to 90 per cent. of the carbon of the semi-coke could be gasified to yield over 400 therms of methane per ton. The effect was even more pronounced with coal, and in addition 5 per cent. of a light tar was formed. With coal, however, the hydrogen developed plasticity, and it seemed likely that the passage of gas through coal on a larger scale would be difficult owing to the fusion of the coal mass. At this stage, therefore, it was decided to construct a semi-scale apparatus to examine the hydrogenating reactions using larger quantities of coal.

The generator which has been built by The Gas Research Board holds a charge of 300 lb. of coal or coke in an 8 ft. vertical column of 12 in. diameter, and the action of hydrogen has been investigated by streaming the preheated gas downwards. A complete understanding of the reactions has not yet been reached, but it has been established that methane equivalent in amount to 110 therms per ton of coal is formed by a reaction wave which moves in the direction of flow of the hydrogen, leaving a residue of highly reactive coke. Some light tar is produced and the formation of ammonia is favoured (tar, 10 gall., sulphate of ammonia, 120 lb., per ton). The rate of passage of hydrogen influences the course of the reactions, but at a rate of 250 cu. ft. per ton per min., the average gas produced contains 28 per cent. of methane and has a calorific value of 530 B.Th.U. This amount of hydrogen could be produced by the gasification of the residual coke (50 per cent.) in oxygen and steam, which suggests an overall yield, on a basis of total gasification, of 210 therms per ton of coal, excluding fuel requirements for steam and oxygen. Further experiment is still required before the two phases of gasification can be conveniently combined.

A second method of gas production has also been explored by The Gas Research Board, primarily as a means of enriching gas of low calorific value, but also as an auxiliary process on a complete gasification scheme. This process is the catalytic synthesis of methane by the Sabatier reaction from mixtures of carbon monoxide and hydrogen.

Researches by the Board have led to the finding of reactive catalysts and satisfactory means for their control, which will ensure a long life at a high space velocity. These results are now undergoing examination in an intermediate-scale apparatus treating 250 to 500 cu. ft. of synthesis gas per hour, and this in turn should lead to the design of a full-scale plant, if this appears to be justified. The percentage of methane in the finished gas depends upon the temperature and pressure employed. To take two examples:—

(1) At 350° C., atmospheric pressure, and a space velocity of 2,000, the concentration of methane in the finished gas is 85 per cent. and the calorific value of the gas is 900 B.Th.U.

(2) At 700° C., 20 atm. pressure, and a space velocity of 7,000, the methane concentration is 42 per cent. and the calorific value of the gas is 550 B.Th.U.

The methane-forming reactions are highly exothermic, 25 per cent. of the calorific value of the synthesis gas being liberated. If the reactions are to be harnessed in processes of gas production, it is apparent that the utmost use must be made of methods of heat interchange and heat recovery.

Processes can be envisaged from the application of the results of both these lines of investigation.

(i) The gasification of coal in hydrogen under pressure to produce town gas and coke.

(ii) The production of the hydrogen necessary for (i) by the gasification of the coke produced, with oxygen and steam.

(iii) The catalytic synthesis of methane as an auxiliary process to (i) and for enrichment of water gas.

Further experimental work is necessary, firstly to obtain a better understanding of the reactions which take place in (i), and secondly to design a reaction vessel in which both (i) and (ii) can be conducted using British coals.

The principal considerations which would justify the introduction of complete gasification in this country are the thermal efficiency of the process, the economics of gas production, greater simplicity of plant leading to reduced capital cost, and greater freedom of choice of coal.

German figures for thermal efficiency, using brown coal, indicate about 62 per cent. (gas/process coal and fuel), excluding a credit of 14 per cent. for tar and benzole. Calculations based on Gas Research Board research indicate 65 per cent. for coal of the Nottinghamshire type, and 70 per cent. if the steam : oxygen ratio should prove to be reducible by operating the generator under ash-slagging conditions. The higher potential efficiency of use of gas, when calculated back to the original coal, makes these figures not unpromising.

The economics of gas production cannot be assessed in the absence of production data for British coal, but it is evident that the cost of oxygen is a factor of prime importance. From German data it would seem that the power requirement of liquefaction plant is about 0·5 kWh per cu. m. of oxygen under the best conditions, and that this represents 50 per cent. of the overall monetary cost. If power in this country is taken at 0·5 per kWh and labour charges are increased, the cost of oxygen works out at not less than 22*d.* per 1,000 cu. ft. So high a figure must call for very serious consideration when the other data become available ; it is unfortunate that there seems no possibility of utilising the separated nitrogen.

It is possible, however, that overall costs of the process would be lower than for existing processes, since it seems certain that the general arrangement of a works would become more compact. In addition, the expensive process of using oxide boxes would be eliminated, and the process of gas purification simplified.

From the national point of view an important consideration is that the use of this process would obviate the necessity for " gas coal " to have either a high caking power or a low ash content, both of which factors are of importance when coke of good quality is to be produced. Of even greater importance is the possibility of building the gas production plant at the colliery and relaying the gas to cities or industry in high-pressure mains.

The possibility of separation of methane by liquefaction for use as a source of fuel or of chemicals still requires further examination, but the storage of liquid methane could provide one method of insurance against times of sudden or high demand for gas. It is an important argument in favour of the continuation of processes of carbonisation that the most economic method of meeting " base " heating loads is by gas, and of meeting peak loads is by stored solid fuel. While it is true that a Lurgi generator can be made to reach full production from cold in 12 to 18 hr., it does seem that liquid methane storage is the only method which promises an efficient substitute for stored fuel.

All these considerations of possible developments in complete gasification must be subject to reservations which can be removed only by further experiment, up to the stage of designing a suitable generator of full size for use with British coals. If the proposals are to be examined thoroughly, as it would seem they must be, it is suggested that the action most likely to lead to a quick evaluation is to obtain a prototype Lurgi generator, examine the behaviour of British coals in it, and proceed to a fresh design as indicated by experience. The generator would require to be accompanied by the ancillary plant necessary for the purification of the gas, and a commensurate oxygen-producing unit. The operation of the prototype unit would provide development information in all aspects of the process. With regard to methane enrichment, the first stage must be the operation of a water-gas plant in which enrichment of the gas is by methane synthesis, and the heat of the synthesis reaction is used for raising steam, the heat of the blow gases being used to preheat air and steam for the generators.

Only the final stages of all these investigations will decide whether a one-fuel or a two-fuel industry is desirable, whether gas storage or greater flexibility in production of gas can be used to meet the peak-load problem instead of coke, and if so, which combination of the processes described above will be most appropriate as a system of complete gasification for industrial application in this country.

(ii) J. E. DAVIS

Dr. King's statement referred to the technical aspects of gasifying coal under pressure. That this is possible with some coals has been proved beyond question by developments in Germany. The technical possibility of carrying out a similar process on the majority of British coals has yet to be demonstrated and this demonstration is a big undertaking. The magnitude of the undertaking should be no deterrent to speed in making the attempt because the potential advantages to the fuel industries and fuel users generally are such as to justify considerable acceleration in the development of a practical process.

The basic problem of fuel supply in this country is similar to that in our general economic situation. We all desire more people to have a higher standard of life despite decreased resources. The higher standard of life implies less work of an arduous nature and more work of a skilled and interesting nature. The solution demands economy in the use of resources and development in technique, for crude metods of application are no longer permissible.

With coal cheap and plentiful as it was in the now rapidly receding past, there seemed little point in economy of use, or in expensive plant and appliances for increasing efficiency or convenience. Today, the position is entirely changed and the change is likely to continue. The increased prime cost of the raw material is the compelling factor towards efficiency and convenience.

The gas industry has grown to its present dimensions because it improves the convenience of fuel supply and utilisation. It economises in the amount of coal needed for the performance of specific operations over a wide sphere and it helps in removing that curse of great cities " atmospheric pollution ". All these three features are intrinsically of the kind demanded by the circumstances of today and tomorrow.

Whether the gas industry should be a one-fuel or a two-fuel industry may not lie with the industry itself to determine but rather with the public which the gas industry serves.

By its present processes the gas industry produces both gas and coke—smokeless gaseous fuel and smokeless solid fuel—and within fairly wide limits can vary the proportions available for sale. To the extent that the public requires solid fuel the production of coke will continue to be an important part of the work of that industry. As long as there can be obtained for coke a good revenue in comparison with the price paid for coal, and if there are available adequate supplies of coal of a quality which produces a good coke, there is not much incentive to depart from carbonisation as the primary process of gas manufacture.

It is well to remember, however, that the chief merit of solid fuels, both coal and coke, is their relatively low cost per thermal unit purchased, but the cost is not as low as it used to be and this fact is leading to a demand for appliances which are more efficient, though necessarily more complicated. There must follow, particularly from the small user, an insistence upon improved quality in the fuel, a call for improved sales service and for consumer service to ensure that the right type of fuel is used in the right way in well-maintained appliances. With the trend in these directions, it is no longer certain that solid fuels will remain low in cost per thermal unit compared with gaseous fuel, whose price already carries such items of service to the customer. Further, a demand for solid fuel (either coal or coke) of high quality can be satisfied only if there is available an adequate supply of selected coals possessing suitable properties. Here, the outlook is not reassuring. The gas industry must, therefore, be in a position to meet a demand for gas increasing more rapidly than the demand for coke and to do so by using not only those coals to which it is accustomed but such coals as are available.

Pressure gasification offers the promise of meeting these requirements, and the development of suitable processes would open a market for gasification plant not only in this country but also, perhaps, in parts of the world where only inferior coal, lignite or peat are available.

Pressure gasification plant for single-stage gasification should be compact in comparison with present plant of similar output and should show a reduction in the weight of solids to be handled per therm made, in the ratio of 5 : 1.

The maintenance of pressure during the production of gas reduces the fall in energy potential and assists thermal economy.

By spreading the inevitable thermal losses of processing over a larger number of therms of gas, the incidence of loss per therm should be substantially reduced and the thermal efficiency of gas production correspondingly increased.

There appears, further, the possibility that if solid fuel is not required in the towns, it may not be necessary to bring coal to the towns, but instead to carry out the gasification at the pithead, for gas generated under pressure can be transmitted over long distances at low cost.

The implications to the coal industry are of particular interest. Already the use of gas and coke for domestic heating enables four tons of coal to do the work formerly done by five to six tons and pressure gasification will reduce this figure to less than three tons. This would result in a reduced tonnage of coal to be mined but if the coal were processed at the pithead the total earnings in the colliery district might well be greater instead of less and there would be provided alternative employment, two factors both tending to increase prosperity in a wide sense.

(iii) H. S. CHEETHAM

While the application of complete gasification in future gasmaking processes must of course depend ultimately upon the advantages of any particular complete gasification process when compared with gasmaking processes already in general use, there are three other aspects of this question which are fundamental. These are—

(1) Whether or not the gas industry is to continue to be a two-fuel industry—producing and selling both gas and coke.

(2) The national policy in regard to the use of imported oil.

(3) The national policy in regard to the domestic consumption of raw coal.

(1) WHETHER OR NOT THE GAS INDUSTRY IS TO CONTINUE TO BE A TWO-FUEL INDUSTRY—PRODUCING AND SELLING BOTH GAS AND COKE

It is recognised that most if not all gas undertakings can today sell all the gas and all the coke they can make from the limited supplies of coal available to them. All such undertakings are " gas-minded " in their view that gas is the main product, but there are some who believe that the sale of gas can be assisted through the broader marketing of gas coke. They contend that although the use of carburetted water-gas as a coal gas auxiliary has greatly minimised the cost of peak load gas, the fact remains that peak load is still much more expensive than base load gas, and that consumers who use the dual service, i.e. gas and coke, and in particular those using gas primarily for cooking and water heating, and coke for background space heating, are in fact easing the demand upon the gas undertaking for peak load gas. Consequently these producers of gas and coke believe that it is preferable to encourage the consumer to provide and finance a portion of his peak load demands by the purchase and storage of reasonable quantities of smokeless coke to supplement the gas industry's more economical supply of gas for cooking and water heating.

There are many others, however, who are of the opinion that gas should and must eventually wholly supersede raw coal and largely supersede other solid fuel for all domestic purposes. They are making great efforts to secure the space-heating load for gas, and claim rightly that the all-gas consumer being relieved of the laborious tasks inevitably attendant upon the use of solid fuel, is prepared to make his contribution towards the cost of peak load gas service.

Apart from the consumer's views regarding his own domestic service, there is no doubt that the all-gas service, by relieving congested streets of the distribution of solid fuel and of the collection and disposal of ashes and clinker, would be of benefit to all.

If the gas industry is to become an all-gas industry, the solution lies obviously in the complete gasification of coal, and later in this discussion the various processes will be considered.

(2) THE NATIONAL POLICY IN REGARD TO THE USE OF IMPORTED OIL

In the light of our present knowledge the only effective method of producing cheap peak load gas is by the strategical use of carburetted water-gas which completely gasifies the coke, excluding coke breeze, produced from the carbonisation of coal, and requires only a modest use of gas oil for enrichment.

One ton of gas oil when used in modern carburetted water gas-plant provides 325 therms of gas as compared with a production of about 73 therms of coal gas per ton of coal carbonised. But this is not the true comparison because the use of gas oil in the production of carburetted water-gas relieves the coal gas plant of the production of peak load gas which wastes solid fuel and does in fact cost several times as much as base load coal gas.

In a typical pre-war year the gas industry carbonised 17,427,000 tons of coal and used 205,000 tons of gas oil in the production of peak load carburetted water-gas. It has been shown that if in this year there had been no carburetted water-gas, the consumption of gas coal would have increased by 2,347,590 tons!

Since under present conditions the demand for coal greatly exceeds the supply, it is indeed a national economy to relieve our coal-gas plants of the peak load service for which they are unsuited by the use of the comparatively small tonnage of gas oil in the manufacture of peak load carburetted water-gas.

(3) THE NATIONAL POLICY IN REGARD TO THE DOMESTIC CONSUMPTION OF RAW COAL

While coke remains in free competition with domestic coal the price of a therm in the form of coke must remain low as compared with the price of a therm of gas. If however, the domestic use of raw coal is prohibited the position will change, and it is conceivable that coke might then be sold at a price much higher than that of coal. In this event the additional revenue to the gas undertaking from coke might be applied to reduce the cost of gas, and thus make it available to consumers who might at present find the cost of an all-gas service to be prohibitive.

Apart from the fundamental questions concerning the sale of smokeless coke, the use of gas oil for the enrichment of carburetted water-gas and the policy regarding domestic consumption of raw coal, it is appropriate to review the more important factors in connection with the various processes or combination of processes already known and in use in the light of their suitability for the production of town gas. Such factors include :—

(*a*) The quality of the gas to be used for town's supply.
(*b*) The reliability of the process.
(*c*) The flexibility of the process, i.e. its ability to meet peak demands.
(*d*) The thermal efficiency of the process.
(*e*) The suitability of the process for the gasification of a variety of coals.
(*f*) The cost of the plant including reserve capacity.

The various processes and combinations of processes which will provide complete gasification are as follows :—

(i) Producer gas process.
(ii) Blue water-gas process.
(iii) Complete gasification process in which the coal is first carbonised and the residue converted to water gas.
(iv) Combined coal carbonising process and blue water-gas process.
(v) Combined coal carbonising process and carburetted water-gas process.
(vi) High-pressure gasification process of the Lurgi type.

(i) *Producer gas process ;* (ii) *Blue water-gas process.*—These two processes may conveniently be considered together since in their application to town gas supply they have almost the same limitations. Both processes are reliable and efficient but they are suited to the gasification of only a very restricted variety of coals and the quality of the gas made is too low for town gas distribution.

(iii) *Complete gasification process in which the coal is first carbonised and the residue converted to water gas.*—Complete gasification plants in which the coal is first carbonised and the residue subsequently converted to water gas have not been installed to any considerable extent. Without enrichment by gas oil the calorific value of the gas produced is little higher at 340–360 B.Th.U. than that of blue water-gas, and the range of suitable coals is considerably restricted. Furthermore, in the light of our present knowledge the maximum size of plant which will operate satisfactorily is too small to be suitable for general use. On the whole, this process does not afford the degree of reliability of the producer gas or the water gas processes, nor is its flexibility as good and the capital cost of the plant is higher.

(iv) *Combined coal carbonising process and blue water-gas process.*—Coal carbonising plant with auxiliary blue water-gas plants are, of course, eminently suitable for carrying out the complete gasification of coal. Both are thoroughly reliable and efficient, but without gas oil enrichment of the water gas the quality of the mixed gas is little higher than that produced by the last process reviewed ; and if the quality of the mixed gas is to be uniform and the whole of the coke production from the carbonising plant is to be gasified, this dual process is inflexible. The variety of coals which may be used is, of course, limited to those recognised as being suitable for carbonisation.

(v) *Coal carbonising process and carburetted water-gas process.*—The combination of coal carbonising plant and carburetted water-gas plant provides for the complete gasification of coal and for the production of a mixed gas having whatever quality may be desired to meet the town standard. Both processes are thoroughly reliable and thermally efficient, and if in periods of low demand for gas some of the coke is stored for use during the periods of peak demand, complete flexibility of output of mixed gas is secured. The carbonising plant is operated always under base load conditions while the peak loads are carried by the C.W.G. plant—balancing both quantity and quality of the gas produced.

While this dual process is capable of the complete gasification of a variety of coals much less limited than in process (iii) the choice is nevertheless limited to " gasmaking " coals.

For the enrichment of the water gas it would be possible to substitute methane, produced by synthesis, for gas oil, and this is a subject which has received much attention by research organisations. For a complete peak load service, however, it would be necessary to liquefy and store methane during the summer months for use during peak load periods, and since this alternative involves an expensive methane liquefaction plant operated at a very low load factor, its use does not appear attractive.

It may be mentioned here that a feature of the process for the synthesis of methane from carbon monoxide and hydrogen is the substantial evolution of heat. In this connection research work is shortly to be carried out by the Gas Research Board having as its objective the use of the heat of reaction of the methane synthesis process in the production of steam while employing the waste heat from the blue water-gas process, normally used for steam production, for the preheating of the air blast and steam used for gasmaking in that process.

(vi) *High pressure gasification of the Lurgi type.*—A type of single unit plant which has been developed in Germany and which has received a good deal of attention in recent times is the Lurgi complete gasification plant in which methane is actually synthesised *in situ.* In this process, which has been discussed by Dr. King, it is possible to produce from suitable coals a gas of town quality without the necessity of the use of oil for enrichment.

On the score of efficiency alone it would appear from the information available that this process is superior to any other single process or combination of processes, but more information is required in regard to its use with British coals.

It is doubtful if the reliability of the Lurgi process is as high as that of other processes in general use today, and in this connection it should be noted that the auxiliary oxygen plant requires a period of some 18 hours for it to be brought into service, and overhaul is necessary after some 200 days' operation.

SUMMARY

Having reviewed briefly the various processes and combinations of processes which effect complete gasification, it is clear that the choice lies between the present accepted combination of carbonising plant and auxiliary carburetted water-gas plant and the Lurgi plant, about which there is as yet only incomplete information available so far as British conditions are concerned.

While the Lurgi plant may show savings in capital cost, its reliability is not as high as carbonising and C.W.G. plants, and if additional reserve capacity is needed to compensate for any lack of reliability, the savings may easily disappear.

It is important that further information on the operation of a Lurgi plant under British conditions be obtained, and accordingly the work proposed by the Gas Research Board should be implemented ; at the same time research and development of existing carbonising and carburetted water-gas processes should continue, for further small improvements may eliminate the difference in efficiency at present in favour of the Lurgi process.

3. Utilisation—Industrial Gas

(Four papers and contributions were presented upon this subject)

(i) H. R. HEMS, ASSOC.M.INST.GAS E., M.INST.F.

CHAIRMAN, INDUSTRIAL GAS DEVELOPMENT COMMITTEE, BRITISH GAS COUNCIL

The development of the use of town gas for industrial processes has been a continual effort to improve the overall efficiency of gas application. Town gas has been and still remains a relatively expensive form of fuel on a thermal basis with the exception of areas with supplies of coke-oven gas available. The combined efforts of gas supply undertakings, manufacturers of furnaces and appliances consuming industrial gas and the industrialist as user or potential user, have necessarily been directed towards continual improvement in the design of burners and furnace equipment to obtain efficiencies as high as possible, commensurate with the requirements of the particular process or trade under consideration.

It would be futile to refer to the valuable advantages which town gas possesses as a fuel compared with other fuels, as, at last, these may be taken as completely recognised by the industrialist. One outstanding advantage has, however, still to receive full appreciation—the fact that gas is essentially a fuel which can be efficiently burned under practically every required condition. In consequence, its field of industrial usage is very wide.

With one or two exceptions, gas is capable of being applied to any heat requirements in industry of whatever calibre or nature, and in many cases it excels by its adaptability and overall economy. In a paper presented to the 82nd Annual General Meeting of The Institution of Gas Engineers, in 1945, which summarised the application of gas in war industry, it was stated that 33 per cent. of all the gas sold in seven important industrial areas of the country in 1943 was used in the factories in those areas.

To meet the widely diverging demands by the thousands of industrial processes requiring heat in factories today, there is a suitable gas burner giving a small pin-point flame for the jewellers' or glass makers' art, through the whole range of blowpipes for brazing, metal cutting, etc., right up to gas burners of heavy consumption with large-volume flame or highly concentrated combustion conditions, as demanded in the reheating and finishing operations of the steel industry.

Gas-furnace practice has generally followed the lines of other fuels in development from direct firing, to systems of recuperation and regeneration which enable the more economic provision of high working temperatures or the maintenance of a given temperature for a lower fuel consumption. Speaking generally, the figure of 10 per cent. which was all that could be expected from the early types of direct-fired gas furnaces, has been raised to 40 per cent. and over by preheating of air required for combustion under recuperative or regenerative conditions in oven furnaces carrying out such operations as steel reheating, annealing and normalising, mainly on a fairly large scale. There is no doubt that in addition to the systems of preheating adopted, the use of improved refractories, metals and insulating materials which have now been available for some years, contributed in some measure to the attainment of the higher figures. The preheating of loads or load recuperation in continuous furnaces of the conveyor or walking-beam types coupled with the benefit of the improved refractories, metals and insulating material also obtains similar improved overall efficiencies of gas application. The use of town gas for steam generation is fairly popular for the smaller boiler units, and the thermal efficiency for this process is much higher than that normally obtained in heat-treatment furnaces.

The commencement of appreciation of the value of town gas in industry coincided with the first world war. Enthusiasts for its development gained much valuable experience between the two wars, revealing its absolute necessity, as recognised by all the Ministries concerned with production, during the last war. This was evidenced by the emergency measures which were taken to ensure its continued supply, and also its restoration as speedily as possible in the event of interference by enemy action. Provision was also made for alternatives in the case of extended stoppage.

The necessity for fuel economy during the latter part of the war resulted in many inspections and close investigations being made into the use of gas in factories. Generally speaking, it may be said that gas was being utilised at the best possible efficiency, and when the appliance-loading was planned to give the minimum stand-by time, the opportunity of making further increase in efficiency was very limited. Where it was possible to economise, this had to be effected by the elimination or restriction of the use of appliances which, from the very adaptability of gas, made it comparatively easy for them to be used for other purposes than those for which they were intended. When inefficiency was apparent it generally resulted from the use of apparatus which had not been kept in a proper state of repair.

The experience of the gas industry at present is that with the closing down of many of the factories producing war material, gas consumption by industry has been reduced, but its recovery has been far more rapid than was expected, no doubt due to the export drive ; and if it were not for the general conditions of labour, fuel shortage, and necessity for repairs to plant, gas undertakings would be able to meet very much heavier demands from industry. It can, therefore, be taken that the industrialist is generally as ready to apply gas to the heat processes for peacetime industry (particularly to meet the heavy requirements of the export trade of the country) as he was to make use of the gas supply for wartime production, and the gas industry is meeting this demand as well as it is able with the conditions under which it is working, and further improvements in burners and equipment for its still more efficient utilisation are being carried out.

The general trend of the use of gas in industrial processes is being influenced by the general economy and planning of practice inside works to an extent which is only just beginning to be appreciated. Reduction of number of hours worked, the likely extension of the five-day week, the shortage of certain types of labour, the realisation that labour will in the future definitely not be available for many furnace-feeding operations, and the general requirements of improved working conditions, are all factors amongst many others, which, in addition to continued increase in price of solid fuels, are leading industrialists to seek a fuel for application to their heating operations which is readily controllable but more particularly adaptable to automatic methods of handling. This is a trend which was well in evidence before the war and received a fillip from the war demand for big continuous production of individual types of munitions, and which will play a most important part in general works practice in the immediate future. The reasons given are undoubtedly responsible for the intense interest which is being shown at present in the various applications of gas to speed heating by concentrated combustion methods, the use of oil fuel, and the direct application of electricity by induction methods of heating. As an illustration of this trend, a proposition connected with the heating of steel pins and bars for forging is interesting. The forging furnaces at present in use are coal-fired and three-sided, each side feeding one or two machines. When each machine is in full production, there is little doubt that the straight substitution of any other form of fuel would be uneconomic, but at present the labour is not available and appears unlikely to be available in the future to maintain the furnaces at full loading, which means that they are generally only feeding two or sometimes even only one machine, the combustion arrangements being such that the furnaces have to be maintained in the condition that would feed all the machines, leading to an overall inefficiency and a very much increased fuel cost on the articles produced.

The suggestion is that by the substitution of gas firing for solid fuel, and taking advantage of the latest methods of gas application, a small unit furnace can be adapted to meet the requirements of each machine, providing quick attainment of the required temperature and the maintenance of that temperature throughout any desired working period to meet the needs of the operator. High overall thermal efficiency may be obtained, resulting in a relatively low fuel cost of article produced in spite of the higher initial thermal cost.

The suggestion put forward has already been successfully tried out with similar projects, and although small batch furnaces are still contemplated in this instance, automatic methods of handling with the necessary gas-burner equipment for speed heating incorporated will almost certainly follow.

The use of gas in industry has been the concern of the gas industry for many years, and a highly organised system exists for the dissemination of information amongst manufacturers whose works may even be situated in the area of a relatively small gas undertaking up to the very large manufacturer in the industrial areas of the country. This is effected by the provision of Industrial Centres whose work is co-ordinated through the Industrial Development Committee of the British Gas Council. The Centres exchange information between themselves and work in close collaboration with research organisations and manufacturers of gas-furnace equipment and industrial appliances, and maintain close contact with the user and potential user to ensure that gas is used as efficiently as possible. Full consideration is given to any new project requiring the use of fuel.

(ii) T. C. BATTERSBY

Previous speakers have dealt with the application of gas in industry from the specialists' viewpoint. May I, as a director of a gas undertaking which has experienced through this demand a very considerable growth, amplify some of the points which have been made and comment on some aspects which affect administration.

It may be fairly claimed that the gas industry has made an appreciable contribution to the decentralisation of industry and the complementary movement of populations. The economic factors which formerly determined the location of so many industries in areas adjacent to the coal-fields are no longer paramount and, subject to the approval of the regional planning authorities, industrialists may establish factories wherever their choice may lead them and in districts where workers are naturally attracted to live. Letchworth and Welwyn Garden City are examples of excellently planned modern towns where rural amenities have been preserved within an industrialised community. Since 1929 the gas consumption in Welwyn Garden City has risen by 336 per cent. and the light industries consume more than 48 per cent. of the total gas demand.

The industrial application of gas requires specialised knowledge and all the large undertakings have created departments for the development of this very important load. Perhaps one of the strongest arguments for integration within the gas industry springs from the desire to improve consumer service. Industrial requirements are more difficult to satisfy than domestic demands, but the limitations of the present structure have not been allowed to jeopardise the extended use of gas in the factory.

The summarised figures show the expansion of the industrial and commercial loads throughout the area served by the Watford and St. Albans Gas Company during the war years :—

	Industrial Gas Per cent. of Total Sales	*Commercial Gas Per cent. of Total Sales*	*Industrial Gas only (millions cu. ft.)*
1939 ..	11·8	7·1	252
1943 ..	20·5	7·5	607
1944 ..	19·2	7·6	615

The dispersal of industry during the war imposed demands upon undertakings which hitherto had been concerned only with domestic consumers, but through the Industrial Gas Centres the engineer of even the smallest undertaking could call in the services of experts, or take prospective consumers to the industrial laboratories of gas undertakings equipped for the study of industrial heating problems. It is a characteristic of the gas industry that information is freely exchanged and new developments are not cloaked in secrecy, except where manufacturers desire to protect their processes.

It is most important that all consumers or potential consumers of gas should appreciate that gas is a refined fuel and its application to each process must be carefully planned for the achievement of maximum thermal efficiency and economy of operation. It is my experience that most industrialists consult the local gas undertaking before installing equipment and very properly demand guarantees of performance and running costs, but in the day-by-day operating it is equally important that the loading of such appliances as furnaces and salt baths is arranged to reduce idle time to a minimum.

In considering gas-firing costs, the charge per therm is not the only criterion; there are many features which should be assessed. Amongst the more obvious of these are ease of control, speed of operation and improved working conditions for employees. Unfortunately maintenance and renewal costs can only be demonstrated after extended operation. One particular example which occurs to me as illustrating this point was that of a manufacturer melting aluminium alloy in 10 cwt. crucibles, who, after converting his furnaces from an alternative fuel to gas firing, found the crucible life to be increased from 30 to 100 melts before renewal became necessary.

The improved factory conditions required under the 1937 Factories Act have had the effect of expanding the space-heating load, but this is less favourable to the production load factor as it accentuates the seasonal variations. Space-heating loads have widened the gap between summer and winter quarter demands upon my own Company. In 1938 the summer quarter was 75·1 per cent. of the winter quarter; by 1945 this had fallen to 72·6 per cent. We should be happier to see this figure rising to 80 per cent. and this may be achieved by the further encouragement of bread baking and similar loads.

The trend towards a shorter working week than generally prevails throughout industry today will widen the variation between the mid-week and week-end loads. To meet this position holder storage will have to be used to greater advantage, stocks being permitted to fall from Monday to Friday evening and built up on Saturday and Sunday.

Except perhaps in the most highly industrialised areas, the falling away of the industrial load on Sundays is a welcome relief to engineers. During the war, when most factories worked a seven-day week, the superimposing of industrial demands upon the domestic cooking peak taxed many distribution systems which in all but the highly industrialised areas are designed to meet the demands of Sunday cooking. Any industrial load which coincides with that peak is not very attractive but conversely all loading off this period will improve the distribution load factor.

Industrialists who have substituted gas for coal have made a substantial contribution to the efficiency of fuel utilisation and to the reduction of atmospheric pollution, but may I stress the imperative need of further action to conserve our only indigenous fuel : (i) By seeing that all equipment is regularly inspected and maintained by experienced technicians and that production is planned to ensure that apparatus is not unnecessarily kept at operating temperatures. (ii) By spreading the demand as far as practicable throughout the working week, industrialists can make a very considerable indirect contribution to fuel economy as gas undertakings will be relieved of the necessity for keeping more plant under heat than is required to meet the fluctuating demands of space heating which, in this country, are unpredictable.

(iii) DEAN CHANDLER

It was the late Lord Melchett who said : " Fuel saving is a practical form of patriotism. It spells efficiency in production and prosperity in national economics."

The fuel efficiency campaign, which was launched by the Ministry of Fuel and Power, as a wartime measure, resulted in considerable saving in fuel. There is every reason for its continuance in the difficult period ahead. Much has been done, but more can still be achieved by attention to equipment. Greater economies will be possible when old equipment is replaced by modern plant.

The application of gas to industrial processes has been a major development of the gas industry in the last thirty years. In that period there has been a great increase in the use of gas for industrial purposes. For instance, in the area of the gas undertaking with which I am associated, the gas used for industrial purposes has increased 800 per cent. since 1914. In some parts of the country 70 per cent. of the total gas made has been used by industry. The reason for this is, I suggest, that gas on tap provides easily controlled heat at the precise point where it is required, the effect of which is :—

(*a*) reduced spoilage, which results in the use of less fuel per unit of saleable product ;

(*b*) reduced damage to the structure of furnaces, thereby lessening the demand for refractories and steelwork which in themselves require fuel for production ;

(*c*) greater control both in operation and adaptation of the furnace to the particular type and quantity of work required, thus permitting closer selection of the furnace capacity to the production programme.

The industrial user of gas who has to effect economy in the use of fuel has at his disposal the wide knowledge of experienced fuel technicians, expert in the application of gaseous fuel, who can give sound advice on the provision and use of appliances of high thermal efficiency for industrial heating. In some processes the efficiency of heat transfer is as high as 90 per cent.

On the non-technical side, the use of gaseous fuel enables clean and healthful conditions to be maintained in a factory, and the fact that gas is available for use at the point where it is required avoids unnecessary labour. An experience illustrates my point : A factory in South London, where soft metals were refined, was having trouble with labour due to the firing of the metal melting pots with coal. Firing by gas was introduced with the result that working conditions were transformed, output went up, and the morale of the workers improved. From the management point of view, as well as from the aspect of saving coal, the striking results were that one therm of gas did the work which previously required four therms in the form of coal, and the over-all cost of the product was lower. This factory used some 600 tons of coal a year prior to the installation of gaseous firing.

This leads me to remark that it is sometimes said that the use of gas as a fuel is costly and, in a competitive field, may be prohibitive. Let me relate the experience of a firm of engineers in the South of England. The problem was to find an efficient and convenient means of stress-relieving steel cylindrical vessels. Having had experience with other fuels used for a similar purpose, the management decided to use town gas in a specially designed furnace. The furnace, 47 ft. long, with a cross sectional area of 225 sq. ft., was completed a few months ago. The maximum loading capacity is 100 tons. The maximum heat input per hour is 120 gas therms. It is estimated that if coal were used, it would require about 200 coal therms to do the same work. The normal working temperature is 620° C. but one section of the furnace can be heated to 950° C. if required. The gas firing is automatically and accurately controlled.

I would like to quote a paragraph from the Report of the Committee of Enquiry on the Gas Industry presented by the Minister of Fuel and Power to Parliament in December, 1945 : " The industrial demands for gas which were growing steadily before the war increased at a great rate during the war, because of the great requirements of the munition and other war industries. Sales of gas for industry are now more than 50 per cent. higher than before the war. It is probable that the conversion of industries from war to peace will mean the loss of some loads for gas, and that some loads which will continue will in time be lost to other fuels when greater freedom of choice allows economic factors to come into play." Our experience in recent months does not wholly support the statement that " some loads which will continue will in time be lost to other fuels when greater freedom of choice allows economic factors to come into play ", for in the case of the second largest gas company in London, and it is that of which I am able to speak with first-hand knowledge, while there was a reduction in the use of industrial gas immediately following the war, today there is a definite trend to use more gas in the industrial field.

The increase in the use of town gas in industry is due in no small measure to the patient research and development work of the industrial gas centres, of which there are eleven. Fuel technologists at these centres concentrate their attention on a wide range of heat-treatment problems and the results of their research and experience are placed at the service of industry.

The gas industry, with coal as the raw material, produces two up-graded smokeless fuels, each of which can be used in a better way than by burning the raw coal. In the process of making these fuels other products are obtained from which a great number of chemicals is produced which play an important part in promoting the health and prosperity of the nation. Thus the gas industry makes a very considerable contribution to the national economy.

(iv) J. WHITE, A.M.I.MECH.E., M.INST.GAS E.

The part of the country with which I am principally concerned, namely, the North-East Coast, is devoted almost entirely to heavy engineering in one form or another, the shipbuilding industry, the glass industry, and a variety of trades which, because of their considerable fuel requirements, have through the passage of time become part of the natural make-up of what may be termed a cheap fuel area. It does not require any great feat of memory to recall good quality industrial coal at 15*s*. 6*d*. per ton or less; indeed such figures were common so little as ten years ago. The former existence of this cheap industrial fuel has had and is still having a considerable effect upon industrial gas technique.

Perhaps one of the greatest contributions which the gas industry has been able to make towards fuel economy and fuel efficiency generally is that in the development of its industrial load it has sought to employ people who would first appreciate the requirements of the process and then to that appreciation add their knowledge of the most appropriate fuel application. The result of this policy has been that the industry has seldom been guilty of attempting to secure loads which were uneconomic from the consumer's viewpoint, and has thus automatically built up an industrial fuel technique which, whilst attractive to the consumers, is equally attractive in the wider picture of effective fuel utilisation. Harking back to the late 1920's and the industrial depression of the 1930's (the years incidentally during which the foundations of industrial gas as it is now understood were established) one could not afford to be profligate with the gaseous therms, especially when heat in the then all-popular solid fuel was available at 0·6*d*. per therm or even less ; consequently " maximum possible efficiency " had to be the code word of the equipment supplied.

One cannot over-estimate the value of knowing what the consumer wants and I often feel that this appreciation can perhaps make a greater contribution towards the efficient utilisation of fuel than any other single item. All too often (especially in heavy industry) circumstances compel the user to think in terms of general utility plant, in other words, of furnaces that will handle forgings from 6 in. × 6 in. to 24 in. × 24 in., and no small amount of ingenuity and practical engineering knowledge is necessary to provide a furnace which can be claimed to be of worth-while efficiency over such a wide range.

One sometimes feels that the term " fuel efficiency " is too narrowly applied. Obviously the minimum number of heat units per lb. of material treated is the true standard of efficiency, but this should surely be coupled with the wider implications of operational efficiency, especially when shortage of production capacity, labour and fuel are a combined drag on the nation's industry struggling to meet the call for vital exports and at the same time to meet the needs of an overwhelming home market. I should like to quote the following case as an example of the contribution which town gas can make in respect of the " three shortages " which I have named. The case concerns a producer-gas fired glass-melting tank furnace used in the production of electric lamps. Firstly, shortage of production capacity : as the result of better control of combustion with town gas than was previously possible with producer-gas firing the output of existing plant is up by 10–12 per cent. which is no small matter when the output is of the order of a million lamps a week. Secondly, saving of labour : again as the result of the conversion, it has been possible to save 360 man-hours a week from the modern automatic producer plant, a figure which would have been considerably greater had the producer plant not been so up-to-date. Thirdly, saving in fuel : the plant previously required 73 tons of coal, or, say, 22,000 therms a week as compared with its present requirements of 15,500 therms in the form of town gas.

Many examples such as this could be quoted over a wide range of industries, but only one further example will be given—because of its importance. Dr. Alexander Fells, at that time of Sheffield Gas Company, when speaking early this year before the Yorkshire section of the Institute of Fuel and referring to one of the largest steel firms in the country, made the following comments :—

> " Every type of reheating and heat treatment of steel is carried out, especially in the heavy section of the industry. From figures made available by the firm's fuel technologist it was shown that 3½ million therms of gas did the same work as 12 million therms of coal."

This superb example sets forward in a very few words the extent to which the carbonising industry can assist in the cause of fuel economy, and it indicates with unquestionable clarity why in the interests of the conservation of the country's primary natural resource the industry must grow and develop upon an ever-increasing scale.

The results to which I have referred have been obtained by the observance of principles which are relatively few in number and may be conveniently summarised as follows :—By the practical understanding of the requirements of the process, by constant research and development, by arranging the mechanism of furnace and allied equipment so that they become, as it were, tooled up into the production line, by the introduction to the fullest possible extent of automatic control, and last, but by no means least, by keeping the furnace and burner equipment simple, robust, and well within the capabilities, mental and physical, of the operator.

SECTION E. THE CARBONISATION AND CHEMICAL INDUSTRIES—*continued*

SESSION II. The Coke Oven Industry

Chairman of Session: MR. G. A. HEBDEN, M.I.CHEM.E., F.INST.F.

CHAIRMAN OF THE FUEL EFFICIENCY COMMITTEE OF THE COKE OVEN INDUSTRY

THE CHAIRMAN opened the session with an account of the work of the Fuel Efficiency Committee of the coking industry. In spite of over-loaded plants and other wartime difficulties, administrative heads and technicians had alike supported the work of the committee. A survey of the industry was made by means of a questionnaire. While this information was under examination members of the committee visited coking plants and found that it would be of benefit to compile a manual or practical handbook for coke-oven operators. This was later issued as the committee's Fuel Efficiency Bulletin No. 1, and had been circulated also in France and the U.S.A. The questionnaire also asked for the thermal requirements of the various batteries stated in B.Th.U. per lb. of coal carbonised, corrected to 8 per cent. moisture (B.S.S. 999). The answers enabled the committee to obtain a comparative assessment of the efficiencies of carbonisation of most of the batteries in the country. A system had been organised by which the underfiring requirements of the batteries were reported to the committee monthly.

All this information was submitted to statistical analysis. A preliminary examination of the data obtained from the original questionnaire circulated to coke-oven plants showed no obvious trend, and of ten possible variables investigated which may influence the efficiency of carbonisation, the only ones showing evidence of a slight relationship were capacity of oven, width of oven and gross coking time. The reason for the failure to obtain good correlation was likely to be due either to unreliability of the data or to missing factors. It had been concluded that work should be done to determine the independent effects of all relevant factors. The data thus accumulated had provided a basis for the paper presented to the conference by Mr. Metcalf and himself.

1. A Modified Method for Calculating the Fuel Efficiency of a Coke Oven Battery

By F. H. METCALF, B.SC., A.M.INST.F.,
and G. A. HEBDEN, M.I.CHEM.E., F.INST.F.

INTRODUCTION

In the carbonisation of coal in a coke-oven battery, heat, produced by the combustion of fuel gas, is applied to coal with the consequent production of coke and gaseous products. Coal carbonisation is a chemical as well as physical process, hence the determination of the thermal efficiency of the process involves the construction of a heat balance containing not only sensible and latent heat measurements but also potential heat measurements both of the coal itself and of its products. Thus, the determination of the actual thermal efficiency of a coke-oven battery is one which bristles with practical difficulties.

From an operational point of view, however, the heat produced by changes in the potential heats of the coal and its carbonisation products is beyond the control of the operator. Similarly, for a given operating schedule, the heat losses due to discharging hot coke from the oven are an intrinsic part of the process and are thus not subject to control. Hence what might be termed the Fuel Efficiency of the battery may be described as the efficiency with which the battery is controlled from a fuel gas combustion point of view.

The heat produced by the combustion of the fuel gas is dissipated in three ways, namely :—

(*a*) Heat consumed by the coal during carbonisation, which includes the heat losses in the coke and by-products leaving the system.

(*b*) Heat losses by radiation and convection from the battery.

(*c*) Heat losses in the products of combustion leaving the battery.

For efficient operation the heat losses (*b*) and (*c*) must be a minimum.

The heat losses by radiation and convection are quite appreciable, being in the region of 13 per cent. of the total heat, but they are not subject to operational control. They can be minimised by attention to pointing, etc., and this question is dealt with in Fuel Efficiency Bulletin No. 1 of the British Hard Coke Association.

The heat losses in the products of combustion escaping up the chimney are, on the other hand, subject to control and from an operational point of view these losses form the main factor when considering fuel economy.

THE FUEL EFFICIENCY OF A COKE-OVEN BATTERY

In this paper we have defined the fuel efficiency of a coke-oven battery as :—

$$\eta = \left[1 - \frac{\text{Heat losses in waste gases per unit volume of fuel gas}}{\text{Heat put into system by combustion of unit volume of fuel gas}} \right] \times 100 \quad . \quad (1)$$

Strictly speaking this is not a true thermal efficiency, but it is a useful guide to the thermal efficiency with which the battery is being operated.

In order to calculate the fuel efficiency it is, therefore, necessary to know :—

(*a*) the heat put into the system by the combustion of unit volume of fuel gas. This is, of course, the calorific value of the fuel gas ;

(*b*) the heat losses in the waste gases escaping up the chimney expressed in heat units per unit volume of fuel gas used. These losses can be divided into two sections—the sensible heat in the gases and the latent heat of the water resulting from the combustion of the hydrogen and hydrogen compounds in the fuel gas. Thus the heat losses may be expressed as

$$H = S(T_2 - T_1)V_1 + H_G - H_N \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where H = Heat losses in waste gases per cubic ft. of fuel gas.

S = Mean specific heat in B.Th.U. per ° C. per cubic ft. of waste gases between T_2 and T_1 ° C.

T_2 = Temperature of waste gases at base of chimney in ° C.

T_1 = Atmospheric temperature in ° C.

V_1 = Volume of waste gases in cubic ft. per cubic ft. of fuel gas.

H_G = Gross calorific value of fuel gas in B.Th.U. per cubic ft.

H_N = Net calorific value of fuel gas in B.Th.U. per cubic ft.

The gross calorific value of the gas used for heating the battery is determined at most coke ovens while the net calorific value is seldom determined. A statistical examination of gases produced at 32 different coke ovens in this country has demonstrated that a close agreement exists between the gross and net calorific values, and an empirical equation connecting the two has been calculated by the method of least squares. The equation is given below and its accuracy can be judged mathematically from the fact that it has a correlation coefficient of 0·949 compared with a theoretically perfect value of 1.

$$H_N = 0{\cdot}897\, H_G - 4{\cdot}3 \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (3)$$

Thus, provided the gross calorific value is known, the net calorific value can be calculated without a knowledge of the analysis of the gas.

The temperature of the waste gases leaving the battery can be determined by the use of a suction pyrometer. The mean specific heat of the waste gases is a function of their temperature and their composition. Knowing these two factors the mean specific heat can be calculated from the equation

$$S = \left(1 - \frac{A}{100}\right)(0{\cdot}03507 + 0{\cdot}000003458\, T_2) + \frac{A}{100}(0{\cdot}03327 + 0{\cdot}000000844\, T_2)$$

$$= (0{\cdot}03507 + 0{\cdot}000003458\, T_2) - \frac{A}{100}(0{\cdot}0018 + 0{\cdot}000002614\, T_2) \quad . \quad (4)$$

Where S = Mean specific heat of waste gases measured at 60° F. and 30-in. Hg in B.Th.U. per ° C. per cu. ft. between 0° and T_2° C.

T_2 = Temperature of waste gases in ° C.

A = Percentage air in waste gases.

The method for calculating the volume of waste gases per unit volume of fuel gas is an adaptation of that outlined by Rosin and Fehling.[1] These authors demonstrated that a linear relationship exists between the net calorific value of a fuel and both its theoretical air requirements and the volume of its combustion products. In the present case similar relationships have been shown to exist between the gross calorific value of a coke-oven gas and its theoretical air and combustion product volumes. The empirical equations evolved have been obtained by the method of least squares from the analysis of gases used at 32 coke ovens in this country, and the accuracy of the relationships is demonstrated by the correlation coefficients which are quoted after the equations which are given below.

$$V_A = \frac{8{\cdot}8865}{1000} H_G + 0{\cdot}6364 \quad . \quad . \quad . \quad r = 0{\cdot}988 \quad . \quad . \quad (5)$$

$$V_O = \frac{7{\cdot}4390}{1000} H_G + 0{\cdot}2407 \quad . \quad . \quad . \quad r = 0{\cdot}979 \quad . \quad . \quad (6)$$

$$A_O = \frac{9{\cdot}1734}{1000} H_G - 0{\cdot}2274 \quad . \quad . \quad . \quad r = 0{\cdot}997 \quad . \quad . \quad (7)$$

Where H_G = Gross calorific value of fuel gas in B.Th.U. per cu. ft.

V_A = Volume of theoretical combustion products in cu. ft. per cu. ft. of fuel gas.

V_O = Volume of theoretical combustion products minus water content in cu. ft. per cu. ft. of fuel gas.

A_O = Volume of air required in cu. ft. for combustion of 1 cu. ft. of fuel gas.

r = Correlation coefficient.

The volume of waste gases per unit volume of fuel gas is equal to the volume of the theoretical combustion products plus the excess air. Hence

$$V_1 = V_A + (n-1)\, A_O \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (8)$$

where 100 $(n - 1)$ = Percentage excess air.

The excess air percentage can be calculated from a knowledge of the oxygen content of the waste gases. On analysis the water in the waste gases is condensed and therefore the oxygen percentage (O_A) is given by

$$O_A = \frac{21\,(n-1)\,A_O}{[V_O+(n-1)\,A_O]}$$

$$\text{or}\qquad (n-1) = \frac{O_A V_O}{A_O\,(21-O_A)} \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

Substituting for $(n-1)$ in equation (8) gives

$$V_1 = V_A + \frac{O_A\,V_O}{(21-O_A)} \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

and similarly

$$\frac{A}{100} = \frac{O_A\,V_O}{[21V_A - O_A\,(V_A - V_O)]} \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

Also substituting for V_A and V_O from equations (5) and (6) in equation (10) gives

$$V_1 = \frac{8\cdot 8865}{1000}\,H_G + 0\cdot 6364 + O_A\,\frac{\left\{\frac{7\cdot 439}{1000}\,H_G + 0\cdot 2407\right\}}{(21-O_A)} \qquad . \quad . \quad . \quad (12)$$

which expresses the volume of the waste gases per unit volume of fuel gas in terms of the gross calorific value of the fuel gas and the oxygen content of the waste gases.

Hence the fuel efficiency of the battery can be expressed in terms of the gross calorific value of the fuel gas, the oxygen content of the waste gases and their temperature by substituting equations (3), (4) and (11) in equation (1) to give

$$\eta = 100\left\{1 - \frac{(0\cdot 103H_G + 4\cdot 3)}{H_G} + \right.$$

$$\left\{\frac{\dfrac{(3507+0\cdot 3458T_2)}{100{,}000} - \dfrac{O_A\left(\dfrac{7\cdot 439H_G+240\cdot 7}{1000}\right)\left(\dfrac{180+0\cdot 2614T_2}{100{,}000}\right)}{\left[21\left(\dfrac{8\cdot 8865H_G+636\cdot 4}{1000}\right) - O_A\left(\dfrac{1\cdot 4475H_G+395\cdot 7}{1000}\right)\right]}}{H_G}\right\}$$

$$\left.(T_2-T_1)\left[\frac{8\cdot 8865H_G+636\cdot 4}{1000} + \frac{O_A(7\cdot 439H_G+240\cdot 7)}{1000\,(21-O_A)}\right]\right\}$$

which will simplify slightly to :—

$$\eta = \left\{88\cdot 8 - \frac{(3507+0\cdot 3458T_2)\,(8\cdot 8865H_G+636\cdot 4)\,(T_2-T_1)}{1{,}000{,}000\,H_G}\right.$$

$$\left. - \frac{O_A(3327+0\cdot 0844T_2)\,(7\cdot 439H_G+240\cdot 7)\,(T_2-T_1)}{1{,}000{,}000\,H_G\,(21-O_A)}\right\} \qquad . \quad (13)$$

As the above equation is rather cumbersome a nomogram has been constructed with a view to simplifying the calculation of the efficiency. The nomogram (Fig. 28)* consists of seven scales and a blank reference line R, and its use is

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* The nomogram as here produced is too small for practical use, but large-scale reproductions of this and similar nomograms for blast-furnace gas and producer gas can be obtained from The British Coking Industries Association.

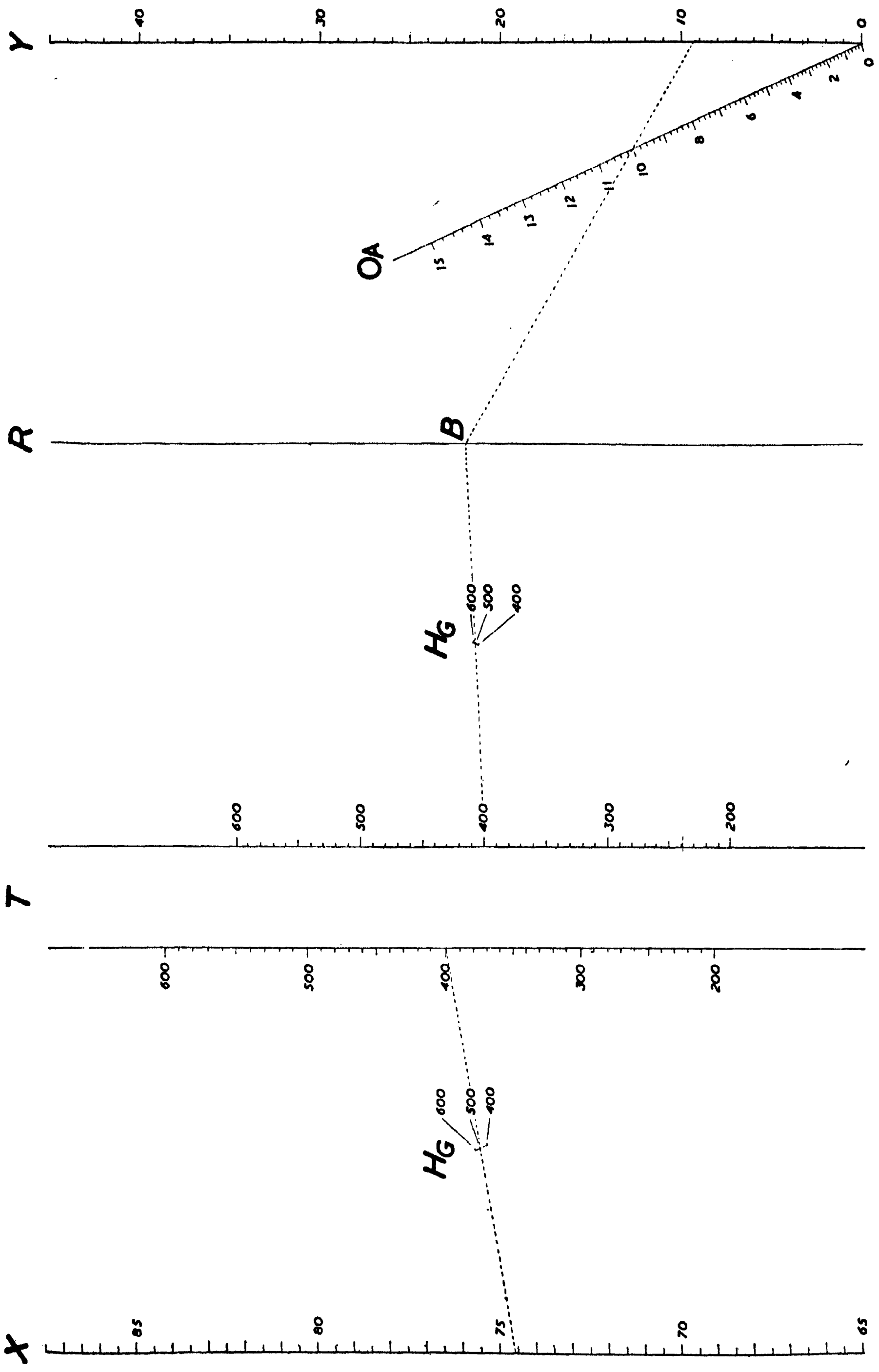
Y
OA
R
B
H_G
T
H_G
X

FIG. 28.

described as follows. Consider a hypothetical case of a coke-oven battery using a gas with a calorific value (gross) of 500 B.Th.U. per cu. ft., a waste gas temperature at the base of the chimney of 400° C., and an oxygen content of 10 per cent. A straight line is drawn from the point 400° C. on the left-hand T scale through the left-hand H_G scale at the point corresponding to 500 until it cuts the X scale. The value on the X scale being noted, in this case 74·57 per cent. Proceeding from the point 400° C. on the right-hand T scale a second straight line is drawn through the right-hand H_G scale at the point corresponding to 500 until it reaches the reference line R at a point B. The point B is then joined through the point 10 per cent. on the O_A scale and the point where the line cuts the Y scale is noted, in this case 9·33 per cent. The fuel efficiency of the battery is then equal to $(X - Y)$ which is, in this case, 65·24 per cent.

EFFECT OF AIR LEAKAGE

Air leaking into the flues and consequently increasing the oxygen content of the waste gases does not affect the value of the fuel efficiency as any increase in oxygen content is automatically compensated by a corresponding decrease in the temperature of the waste gases. This only applies to air leaking into the flues after the waste gases have left the regenerator. Air leakage prior to the gases leaving the regenerators lowers the temperature of the gases in the regenerators and, therefore, robs the regenerators of a certain amount of heat. In that case both the oxygen content and the temperature at the base of the chimney are high thus giving a low efficiency.

BLAST-FURNACE GAS

The same theory can be applied to blast-furnace gas and empirical equations have been calculated from a series of 39 analyses, obtained through the courtesy of Mr. E. C. Evans of the Iron & Steel Industrial Research Council.

The equations are as follows and the degree of correlation is again remarkably good.

$$H_N = 0{\cdot}970\, H_G + 1{\cdot}7 \quad . \quad . \quad . \quad r = 0{\cdot}997 \quad . \quad . \quad (14)$$

$$V_A = \frac{6{\cdot}364}{1000} H_G + 0{\cdot}958 \quad . \quad . \quad . \quad r = 0{\cdot}988 \quad . \quad . \quad (15)$$

$$V_O = \frac{5{\cdot}736}{1000} H_G + 0{\cdot}995 \quad . \quad . \quad . \quad r = 0{\cdot}958 \quad . \quad . \quad (16)$$

$$A_O = \frac{7{\cdot}262}{1000} H_G + 0{\cdot}023 \quad . \quad . \quad . \quad r = 0{\cdot}998 \quad . \quad . \quad (17)$$

In the case of blast-furnace gas the mean specific heat of the theoretical waste gases is given by

$$S = 0{\cdot}03485 + 0{\cdot}000007374\, T_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (18)$$

Hence, similar to coal gas, the final equation for the efficiency becomes

$$\eta = \left\{ 98{\cdot}7 - \frac{(3485+0{\cdot}7374T_2)\ (6{\cdot}364H_G+958)\ (T_2 - T_1)}{1{,}000{,}000\ H_G} - \frac{O_A(3327+0{\cdot}0844T_2)\ (5{\cdot}736H_G+995)\ (T_2-T_1)}{1{,}000{,}000\ H_G\ (21-O_A)} \right\} \quad . \quad (19)$$

A nomogram covering this equation has been constructed, and this is operated in the same manner as that constructed for coal gas.

PRODUCER GAS

A series of 44 analyses of producer gas, obtained through the courtesy of Mr. G. W. J. Bradley, of The Grassmoor Co., Ltd., have been subject to similar statistical treatment to give the necessary empirical equations, which are as follows :—

$$H_N = 0{\cdot}920\ H_G + 4{\cdot}34 \quad . \quad . \quad . \quad r = 0{\cdot}997 \quad . \quad . \quad (20)$$

$$V_A = \frac{10{\cdot}770}{1000} H_G + 0{\cdot}491 \quad . \quad . \quad . \quad r = 0{\cdot}971 \quad . \quad . \quad (21)$$

$$V_O = \frac{8{\cdot}477}{1000} H_G + 0{\cdot}579 \quad . \quad . \quad . \quad r = 0{\cdot}964 \quad . \quad . \quad (22)$$

In the case of producer gas the mean specific heat of the theoretical waste gases is given by

$$S = 0{\cdot}03480 + 0{\cdot}00000336\ T_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (23)$$

Hence the final equation for the efficiency becomes

$$\eta = \left\{ 95{\cdot}2 - \frac{(3480 + 0{\cdot}336 T_2)\ (10{\cdot}77 H_G + 491)\ (T_2 - T_1)}{1{,}000{,}000\ H_G} - \frac{O_A (3327 + 0{\cdot}0844 T_2)\ (8{\cdot}477 H_G + 579)\ (T_2 - T_1)}{1{,}000{,}000\ H_G\ (21 - O_A)} \right\} \quad . \quad (24)$$

The nomogram for solving this equation is operated similarly to that for coal gas.

Discussion

Dr. Rosin : My work on the I_t-diagram aimed at eliminating the tedious combustion calculations by using the statistical relations between the calorific value, air requirement and volume of waste gases of fuels, and by correlating the heat content and temperature of such waste gases. The original work was based on the net calorific values, the figures for the air requirement and waste gas volume based on the gross calorific value, and the statistical equations derived therefrom are, therefore, a most valuable extension of the I_t-diagram. The authors' nomograms will be useful not only in the carbonising industries but wherever these fuel gases are used.

The statement by the authors that the first step to fuel economy is the construction of a heat balance will be generally agreed. We should consider furnaces as heat engines and remember that the great development of the steam engine took place when, by the work of Carnot, Clausius, Rankins and others, it became possible to produce a proper heat balance and to correlate the actual to the maximum obtainable power output. The authors present the heat balance of a coke oven in the form of an efficiency coefficient by relating the heat lost in the waste gases to the calorific value of the fuel. Unfortunately, there is in the furnace industry no general agreement on the definition of thermal efficiency, and misunderstandings are likely to arise therefrom. It would be very valuable if this session would contribute to a clarification of the term " thermal efficiency."

The authors' equation 13 consists of two terms, one being constant, the other containing a temperature difference $T_2 - T_1$. The second term will become 0 if $T_2 = T_1$, and the efficiency will then be 88·8 per cent. but not 100 per cent. It differs from 100 per cent. by the amount by which the gross calorific value differs from the net. This means that the theoretically obtainable maximum efficiency is not 100 but only 88·8 per cent., and the actual efficiency must be appraised in relation to this fact. In the first example, the calculated fuel efficiency is 65·24 per cent., but if related to the maximum possible efficiency of only 88·8 per cent., it becomes 73 per cent. We have here a similar case as with the regenerator efficiency to which Mr. Finlayson has referred in his recent paper (Institute of Fuel, February, 1946) pointing out that the percentage of heat recovered should be related to the theoretically possible.

Such proper relation is the more necessary as the difference between gross and net calorific values, which is the amount by which the theoretical efficiency differs from 100 per cent. is different for the various fuel gases owing to their varying hydrogen content. Thus, the theoretically possible efficiencies are :—

For coke-oven gas	89 per cent.
For producer gas	95 per cent.
For blast-furnace gas	99 per cent.

and it will be necessary to keep these figures in mind when assessing the efficiency figures calculated by the method of the authors.

Finally, I hope that the authors will agree with me if I read some qualification into their statement that the heat losses by radiation and convection are not subject to operational control. They are dependent on time and, inasmuch as it is possible to shorten the time of a carbonising cycle, their percentage related to the total heat input will become smaller. In our endeavour to save fuel, the time factor should receive our greatest attention.

Mr. W. F. Carr : Recent work of the British Coke Research Association through one of its panels which is dealing with the specification of uniform methods of determining and reporting yields of coke and by-products from a defined coal, has shown that accurate estimation of even straightforward weight balances on a plant scale presents considerable practical difficulties. It is obvious that when the determination of operating efficiency is being considered these difficulties must inevitably be extended when any form of measurement of thermal balance is being attempted. The paper will prove to be a most useful and practical aid to achieving greater thermal efficiency. I would ask a question on the practical application of the method : Where considerable air leakage occurs in the regenerator, is it possible to apply the method to the ovens alone ?

Dr. I. F. K. Th. van Iterson considered an important question to be that of gas leakages from the oven chamber into the flues. In calculations on efficiencies, how could the gas which had leaked through the walls be separated from that which had gone through the burners ?

Mr. Curry asked (*a*) what was the average value of fuel efficiency as derived by the above method ? (*b*) What maximum variation could be expected on a plant ?

Mr. Metcalf believed, in answer to Mr. Carr, that it would be possible to measure the efficiency of coke-oven batteries without regenerators, but if this were done, due allowance would have to be made and measurements taken of temperature of air in and out of regenerator, temperature of gas in and out of regenerator and some measurement made of volumes.

Replying to Dr. van Iterson, the gas coming through the oven wall would have a higher C.V. than that being burned in the flues. It would be difficult to assess the actual C.V. but the error in any case would not be very big.

For every increase of 10 B.Th.U. in the C.V., there would be an 0·2 per cent. increase in efficiency so that with 100 B.Th.U. increase and no allowances made, the percentage error would be only about 1·5 per cent.

Replying to Mr. Curry, the average value was somewhere between 70 and 75 per cent. This was too low ; it should be up to 80 per cent. The maximum variation on test was 1–2 per cent.

Reference

1 " Das It-Diagramm der Verbrennung " V.D.I. Verlag, G.m.b.H. Berlin, 1929.

2. Memoranda on Practical Fuel Economy—Procedure for Coke Oven Plants

FUEL EFFICIENCY BULLETIN No. 1 FOR THE COKING INDUSTRY

A discussion on this bulletin was introduced by Mr. G. H. Harrison.

Mr. G. H. Harrison said that, as the chairman had explained, this bulletin briefly set down those requirements which the committee considered to be of the greatest importance in achieving good operating technique. Its keynote was " schedule ", not only in the limited sense in which the term is used in the coking industry, but in the broader general meaning of systematic planning, regularity and consistency. To operate any system satisfactorily, adequate information must be readily available in order that fluctuations in performance may be appreciated and their character and importance quickly assessed. Whilst it was realised that the technical skill and practical experience of the operating personnel was the primary requirement in this respect, it was nevertheless essential that the plant should be adequately instrumented in order to provide regular data which could be recorded and subsequently interpreted by the operating staff. This could not be over-emphasised. There were still plants in existence at which there was no direct measurement of the fuel gas used to heat the ovens.

The condition of the coke during discharge was the chief indication whether the charge had been correctly or incorrectly heated. Uniform heating from top to bottom and from end to end of the ovens should be the first aim, and minimum fuel gas consumption to achieve the required uniformity should be sought.

Economy in the use of fuel gas could best be obtained by charging and discharging the ovens according to a time schedule. The coal charge for each oven should be weighed to ensure that each of the ovens contained approximately equal amounts of coal, and there should be a constant flow of fuel gas determined for the particular schedule. Control of fuel gas consumed was best obtained by use of gas meters and automatic pressure regulators.

In addition to the actual measurement and the pressure control of the fuel gas supplied, the correct combustion conditions within the heating flues must not be overlooked as this influenced to a great extent the amount of gas needed to attain the heat required for carbonisation. The proper gas/air ratios could only be determined with any degree of accuracy by means of analysis of the flue gases. Once more, " schedule " was important and such analyses should be a routine part of the operating procedure. To ascertain whether the fuel gas was burning to the best advantage, regular and frequent inspections of the heating flues should be made and there should be close observation of the hot coke. The degree of uniformity of heating could then be assessed and the necessary adjustments made on the individual flues.

Regular and systematic readings should be taken of the flue temperatures using a pyrometer to ascertain any abnormal conditions. The value of daily visual examinations of the main parts of the battery was generally recognised, and of equal importance was the cleaning of the mains and regular attention to cleaning ascension pipes and fuel distribution pipes. Special attention should be paid as a matter of routine to the pressure in the collecting mains ; this should be kept constant at the figure found to give the best conditions in the oven chambers. The pressure conditions in the oven chambers could easily be determined by taking readings during the carbonisation period. In the bulletin it was suggested that in general the collecting main pressure should be not less than 3 mm. water gauge and should have a maximum variation of no more than ½–1 mm. water gauge. Recent work by the British Coke Research Association upon the incidence of damage to coke oven ends, had shown that batteries working with collecting main pressures between 3 and 5 mm. w.g. were subject to considerably less damage than batteries working with collecting main pressures less than 3 mm. or above 5 mm. w.g.

The measures described in the bulletin were now being generally applied in the industry, but there were still many opportunities for improvement both in large and small details. Particular attention was directed to small matters involving little or no major alterations in which by attention to detail and system important cumulative savings could be effected. Since the coke-oven industry consumed over 10 per cent. of the total coal produced, even the smallest general improvement would affect very considerable total savings.

Mr. N. Warwick (President, Coke Oven Managers' Association) welcomed the tribute paid by the Chairman to the members of his Association, who had carried out very arduous duties during the war. The policy of the C.O.M.A. was progressive and the members felt that by applying their energies towards processing coal resources in coke ovens to the best advantage they would assist materially in restoring the prosperity of the country. Bulletin No. 1 was not written as a text-book but as a refresher upon good routine practice. He desired to confine his remarks to the future. Here, the position should quickly be reached at which everything possible had been done to reduce heat losses from existing plant and new fields for heat saving must be planned to achieve real efficiency. Mr. Warwick proceeded : We must do something about old plants, and also about radiation, convection and waste heat losses from the new plants being contemplated. In this country there is a tendency to use industrial plant until it will hardly produce any longer or the establishment cannot show reasonable profit because of high costs, brought about by falling outputs. Many of us take too literally the viewpoint that it is no use having efficiency, if such efficiency is not economical. The *initial* cost in purchase of new plant that is efficient is usually the only reason why it is turned down on economical grounds. Such parsimony will jeopardise successful application of the discoveries through research for fuel saving designs in carbonising plant. I suggest that with dwindling coking coal resources and the inadequate level of coal production as against coal consumption, a target might be set for efficiency of coal carbonisation in the future. If by proper operating technique it is not possible to reach that standard, the equipment should be replaced by plant of new design which is not wasteful from our viewpoint. I do not say there should be fewer plants ; geographical position and the livelihood of existing trained labour determines the necessity for the continuance of these, but what plants there are should be good.

It is, as Mr. Harrison points out, necessary to look for savings, however small, in view of the accumulative effect over the whole industry's fuel consumption, but if we took a target saving of as high as 10 per cent. for the industry as a whole there may be 20 per cent. of useful therms escaping up the chimney through use of worn-out and dilapidated refractories on some plants, or considerably more than 15 per cent. of the fuel consumption lost through radiation and convection.

There are so many features of the coke oven where something can be done in the future.

The lack of interest in dry cooling of coke in my view is to be deplored. Here we are losing something like 5 per cent. of the calorific value of the coal through not making use of the sensible heat in the coke. At least 1,000 lb. of steam per ton of coke is available, which on quite a moderate sized coking plant would reach 25,000 lb. an hour at 200 lb./sq. in. pressure. This can be used to supply all the requirements of the plant—or generate power and give surplus energy for other uses—and this steam can be provided at a cost well below boiler practice.

Return of capital expenditure for dry cooling has been stated to exceed 20 per cent. but designers have not had the opportunity of developing this heat saving process because of first cost. I feel that improved dry quenching systems would be economical. There are coke-oven plants which buy their steam, or have installed separate boiler plants because they felt that dry cooling was not sufficiently advanced. Here is scope for the future. If something could be done to eradicate what I term the wretched red herring of initial and competitive cost as regards coke ovens, we would get somewhere and show the carbonising world something in fuel saving and coking technology.

Finality in research work on improving the coke oven from the fuel saving viewpoint is restricted through competent designers being restricted to providing lowest capital cost design.

My company have recently taken out a heat loss survey of all the ironwork on an average age coke-oven battery and, whereas at first study it seemed a difficult undertaking, I was surprised how easily this type of investigation work can be done. In the heat loss calculations we used the formulæ in Fuel Efficiency Bulletin No. 17 published by the Ministry of Fuel and Power. The losses from door frames, buckstaves, etc., approximated to the figures already published in our own Fuel Efficiency Bulletin No. 1, but on measuring the B.Th.U. per sq. ft. heat loss from the leveller doors I was shocked. Although this is a relatively small area for loss to occur, compared with the structure as a whole, nevertheless it was something that we had lived with for fourteen years and illustrated how serious indifference or ignorance could be to heat consumption ; and here is a point where we thought present design was good enough. But it doesn't really require a calculation to tell you where heat is being lost, you can feel it, even on the latest and so-called modern coke-oven structures. A five minutes sojourn on the top of a battery on full output burns the soles off your shoes. It is not an odd brick you are standing upon—the area of a fairly average size battery top can be 10,000 sq. ft. Pick up a bar which has been left against the battery steelwork and you drop it quicker than you picked it up. It is not uncommon for a 2-in. thick metal one-piece door frame to have to suffer a temperature differential of 600° C. These things are wrong in 1946.

I have roughly calculated that on a large battery the heat loss from all the ironwork can reach a coal equivalent to 4 to 8 tons coal a day dependent on its age and design, or 1,460 to 2,920 tons a year. Now if we took a mean figure of 2,190 tons per plant, on 89 plants this gives 195,000 tons for the industry. On the assumption that the average efficient life of a coke-oven battery is 15 years, and that design improvements were made now, we could say that in 15 years the industry would be saving a considerable tonnage of coal from this and other sources of heat loss. The coking industry is quite as efficient as other industries, at least according to present-day standards, but this should not close our eyes to the fact that there is a solution substantially to reduce heat losses, if the initial cost objection is dealt with.

To summarise, I would submit that, as far as concerns coke-oven heating, we cannot reach the state where we are making the best use of coal unless :—

(*a*) We operators enthusiastically keep a constant look-out every day for all avoidable sources of heat loss.

(*b*) That designers follow a thermal specification for coke ovens, so drafted to give effect to the substantial further reduction of existing heat losses.

3. The Influence of Moisture Content of Coals on Coke Oven Operation

FUEL EFFICIENCY BULLETIN NO. 2 FOR THE COKING INDUSTRY

Mr. G. W. J. Bradley, introducing a discussion on this bulletin, made it clear that the bulletin was a guide, not a set of instructions. The bulletin, he said, confined itself to coke-oven procedure, although there were many other factors concerned with moisture in coal. The cost of cleaning and drying should concern those who sell the coal, not those who purchase it. The conclusions reached in the bulletin were as follows :—

(1) The increase in fuel gas requirements with increase in moisture content of a coal does not in many cases become appreciable up to 9 per cent. moisture.

(2) Variations in moisture content, especially within a given oven, result in a reduction in under-firing efficiency and deterioration of oven brick-work.

(3) High, uniform moisture contents, especially of coal of large particle size, result in draining in the ovens immediately after charging, and may cause considerable damage to the lower courses of oven bricks.

(4) Low moisture contents of 4 per cent. or less, frequently result in charging difficulties due to the evolution of dust laden gas, and tend to cause increased damage to buckstays, flash-plates and jamb brickwork. Such low moisture contents increase the bulk density of the charge and may result in greater throughput although the swelling pressure of the coal tends to increase with bulk density.

(5) The use of bunkers or draining towers for preliminary coal drying is desirable, but, unless the coal contains a low proportion of fines or is of low moisture content, this treatment should be followed by some other method of de-watering.

(6) The results available from plants which have installed dryers indicate that the generalised conclusions given in this report concerning heating requirements and throughput of ovens are substantiated and that at these plants the installation of dryers has proved a success.

Mr. Carr felt that some important matters had been omitted, particularly (*a*) de-dusting prior to washing and adding back the dust, and (*b*) the clarification of washery water, by which means it was possible to reduce the moisture content by 4 per cent.

Mr. Bradley agreed that both these measures were desirable, but emphasised that it was the coke-oven manager who should make the decision whether or not to add back the dust.

Dr. van Iterson discussed the differences between British and Dutch practice. In Holland, half the coal for carbonisation was derived from froth flotation plants, so that it was very fine in size and to it was added the ground middlings. The problem of preparing coal for carbonisation was thus very considerable. On his plant, 2,000 tons of slurry with an average moisture content of 25 per cent. were added back each week. The best system was found to be to dry the fine coal by centrifuge, to dry froth-floated coal initially by vacuum dryers completing by thermal drying with pulverised fuel firing ; the whole was then mixed in mills and had a final moisture content of 12 per cent. Large flocculation plants were installed in Holland to prevent pollution of streams, but the only useful product obtained from them was clear water as the filter cake had an ash content of over 80 per cent.

Mr. Harris asked for the different costs of the methods of drying described in the bulletin—de-watering screens, bunker or drainage tower, centrifuging, vacuum filter, thermal drying.

Mr. Bradley said that in drying by bunkers the cost was mainly capital cost. On his plant the cost of centrifuge drying was 2·27*d.* a ton, excluding capital cost.

Mr. Damon regarded the coke-oven industry with favour because it produced two smokeless fuels, but unfortunately the manufacture of those fuels led to considerable atmospheric pollution. Steam jets and other suction devices had been used but with little improvement. He asked what was being done on new batteries.

Mr. Marshall said that on his plant a system of thermal drying had been introduced in 1939 using the flue gases from the ovens in rotary dryers for the removal of the surface moisture and part of the inherent moisture. One reason for the adoption of this system was the difficulty of handling wet dust. In this method the gases were reduced in temperature to below 100° C., and since the dewpoint was 40° C. there had been no corrosion trouble. The coal had been dried to such an extent that moisture had to be added back to permit successful handling.

Dr. A. Crawford drew attention to German practice as disclosed by B.I.O.S. reports. Dr. van Iterson had referred to vacuum drying to 20–25 per cent. moisture followed by thermal drying in horizontal drums. While it was important to remove as much moisture as possible by mechanical means, the foregoing figures seemed to be about the limiting values for vacuum filtration. Centrifuges developed by the firm of Escher-Wyss of Zurich and Ravensburg gave better moisture reduction, down to 12 per cent. for coal of size below 0·5 mm. These centrifuges differed from the more normal types in being mounted on a horizontal axis. They were intermittent in action, but this disability was offset by the fact that they were completely operated by adjustable automatic controls, the filling, centrifuging and discharging periods being variable at will. Charging and discharging were effected without altering the speed of the machine. The machine consisted of a perforated steel basket lined with wire mesh or fabric filter cloth. The centrifuged cake was removed by a hydraulically operated scraper knife. As the power input curve for a single machine varied with the filling, centrifuging and discharging operations it was customary to make the larger machines double-ended, the two baskets being operated in opposite cycles. The reason for the higher efficiency of moisture removal was that whereas vacuum-operated filters were limited to pressures on the filter cake of 0·5 kg/sq. cm. centrifuges developed pressures of the order of 12 kg./sq. cm.

Dr. van Iterson said that he was acquainted with the Escher-Wyss system since it was used for drying sulphate of ammonia. He did not think that fine coal could be successfully dried by that system, and maintained that drying to 20 per cent. by vacuum followed by thermal drying was the best system.

Mr. D. T. Barritt, answering Mr. Damon, said that smoke developed during charging the ovens was being dealt with in new designs of plant, along four main lines : (*a*) By adoption of the two-main system, (*b*) by the greater use of telescopic chutes on the charging car, (*c*) correct spacing of the charging holes and (*d*) speeding-up the charging operation. The problem was most acute with dry coal, but with moisture contents of 8–10 per cent. it was possible to charge almost smokelessly. Other systems, such as the use of a single charging hole, were under investigation, but the levelling period would be thereby extended. His view was in favour of the two-main collecting system.

Dr. H. H. Lowry wrote : It is difficult to accept the thesis stated in Bulletin No. 2 that reduction in moisture content below some critical figure, e.g. 8 ± 1 per cent., does not result in a decrease in fuel gas requirements. The graphs of Litterscheidt (referred to in the bulletin) are based on data obtained by Baum (Bulletin, ref. 7). Careful examination of Baum's original data (K. Baum, Arch. Eisenhüttenw., **2**, 779–794 (1929) & **6**, 263–9 (1933)) do not appear to justify the curves as originally drawn and accepted by Litterscheidt and others. Furthermore, analysis of data of the U.S. Bureau of Mines obtained in carbonisation on 30 coals, ranging in moisture content from less than 1 per cent. to more than 10 per cent. (c.f. Fieldner and Davis, U.S. Bur. Mines Monograph **5** (1934)), indicates that there is a proportionality factor relating heat requirements with moisture content with no sign of a critical value. (Lowry, London and Nagle, Trans. Inst. Mining Met. Engrs., **149**, 297–326 (1942)). A more detailed discussion of this subject is given in a chapter of the recently published " Chemistry of Coal Utilisation " (Lowry, Chap. 23, Vol. 1, 848–862 (1945).

Dr. G. E. Foxwell wrote : I do not think Dr. Lowry's view can be accepted without further proof. The late Dr. Koppers always affirmed to me that his practical measurements on coke-oven plants and his calculations showed conclusively that moisture content of the coal as charged (provided the moisture was uniformly distributed so that no considerable portions of the charge were above 8 per cent. moisture) had no effect on the fuel consumption. That he based his guarantees on this assumption without incurring penalties, is evidence that he was right. The evaporation of moisture by the sensible heat of the gases generated from the coal depends upon the flow of gases, and it has always seemed to me that until the Bureau of Mines performs its experiments on full-scale coking plants, their conclusions cannot be regarded as more than tentative and as accepted subject to later confirmation from practice.

4. A Consideration of the Bulletins of the Fuel Efficiency Committee of the Coking Industry from the Plant Constructor's Viewpoint

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When the authors of this paper were invited to present jointly a short contribution to this conference on fuel efficiency they came to the conclusion that a useful purpose might be served if they gave some consideration to the bulletins of the Fuel Efficiency Committee of the coking industry, looked at from the coke-oven plant constructor's viewpoint. In the first place it should be recorded that the preparation and circulation of the bulletins are themselves an indication of the improved co-ordination and efficiency of the coking industry. At one time the coking industry appeared to the plant constructor as a number of isolated units, with little exchange of ideas and information. The formation of the British Coking Industry Association, with its various technical committees, and in more recent times the establishment of the British Coke Research Association, have played an important part in securing much closer contact between the technical men in the industry. The plant constructor by reason of his travels through the industry is well placed to judge the extent to which this collaboration has progressed and the benefits which have resulted. The authors greatly value the opportunity they have been given in taking part in the recent efforts towards technical collaboration in the coking industry.

In order to appreciate each other's problems it is essential for the plant designer and the plant operator to collaborate, not only when the plant is being designed but during its working life. Experience in the operation of a plant over prolonged periods is of the utmost value to the constructor in the designing of his future installations. Progress depends so often on the improvement of small details. The plant designer therefore welcomes at all times the criticisms and opinions of those who operate the plants he has built. The authors cordially welcome the formation of Panel 6 of the British Coke Research Association which has been formed to deal specifically with practical plant problems. The work of this panel is already being reflected in new plants now under construction.

MAIN FACTORS IN DESIGN

In designing a new coke-oven installation the designer's main object is to produce coke, gas and by-products in the maximum quantity and of the desired quality. In order to achieve this he is faced with balancing various factors some of which may be conflicting. The four main factors are :—

(*a*) The minimum consumption of fuel gas.

(*b*) A sound and robust structure which will not only sustain a high performance over the working life but which requires the minimum of maintenance.

(*c*) The minimum expenditure of physical effort on the part of the operating personnel and the provision of comfortable working conditions.

(*d*) The lowest capital cost.

It is evident that these factors are inter-related and that their relative significance may alter with change of circumstances. For example, the first two factors are closely related to capital cost. As regards the third factor, a reasonable standard of convenience and comfort can usually be obtained at moderate cost, but over-elaboration can be expensive. Special circumstances may alter the designer's outlook. In the days when coal was cheap and there was little outlet for surplus coke-oven gas, there was no need to improve thermal efficiency and spend money on so doing. These circumstances do not and probably never will again apply to this country, but they are still occasionally encountered elsewhere and have to be dealt with. The authors have knowledge of a large waste-heat battery now being built abroad where coal is so cheap that it does not even pay to instal waste-heat boilers. Or again, in times of trade depression there is a tendency to reduce the capital cost of a new plant to the minimum, with consequent adverse influence on fuel efficiency, maintenance cost and comfort conditions. A further example is the present tendency towards building a large coke-oven installation in the form of a number of small batteries to facilitate the rebuilding of the ovens with a minimum disturbance in output. This method of construction has an adverse effect on fuel consumption although achieving its main object.

The position in this country today needs no comment. The shortage of coal, its high price, and the demand for coke-oven gas make it essential that every new plant shall be designed for maximum thermal efficiency. The need for attracting the right type of operating personnel, able and willing to run the plants to the best advantage, places a duty on the designer to eliminate as far as possible unpleasant work and unnecessary effort. The fact that increased thermal efficiency and to a lesser extent improved working conditions result in greater capital expenditure is unfortunate at a time when construction and material costs are high, but this is a burden which falls on all industrial enterprises with the same ends in view.

GENERAL PRINCIPLES OF OVEN DESIGN

Improved working conditions are already being studied in detail by Panel 6 of the British Coke Research Association and we do not propose to deal with this large subject in a short review. Better thermal efficiency is, however, primarily the concern of the designer. How does he set about his work ? First of all he must recognise that coking coals vary considerably in their properties and in the treatment they require to produce coke suitable for different uses. He must therefore envisage the coking of a given coal or blend of coals under specified conditions to give the product required. It is not usually possible to regulate a plant to give the best results under conditions widely varying from those for which the plant was originally designed. There are several general principles which he must observe in whatever design he offers. They are :—

(1) The heating system must be such that, assuming the coal charged is uniform in all respects, coking is simultaneously completed along the length of the charge. If it is not, some part of the charge will be overheated and fuel gas thereby wasted, while the remainder of the charge is being carbonised.

(2) The level of the top of the heating flues must be correctly located to suit the characteristics of the coal charged.

(3) The regenerators must be designed and proportioned to work at high efficiency ; that is, the heat imparted to the ingoing air (and lean gas in the case of compound ovens) must be as near the theoretical as possible.

Commenting briefly on these factors in order :—

UNIFORMITY OF COKING

The taper of the charge demands the correct graduation of temperature from ram side to coke side for simultaneous completion of coking without waste of fuel gas. All oven systems provide means of doing this. With rich gas-firing, replaceable nozzles are provided for each flue and a good degree of accuracy in distribution is thereby obtainable.

Distribution of air and lean gas supplies in their correct proportion is achieved by balancing the upstream and downstream regenerator sole flues, supplemented in some cases by the use of dampers at the top or bottom of the heating flues.

The correct use of these various devices is a matter of trial and adjustment. Whatever system is available, the right procedure where maximum fuel economy is desired is to use a pyrometer and an Orsat apparatus to make adjustments to give not only the desired flue temperature but also a constant and minimum excess air. The labour involved in this work is well worth while. Once the proper cross wall conditions have been established it is rarely necessary to make readjustments.

LEVEL OF THE TOP OF THE HEATING FLUE

The necessity of fixing the top of the heating flue at the correct level is generally agreed. It is sufficient to say here that if the level is too high to suit the particular coal carbonised, the gaseous products will be degraded with formation of roof carbon, and the free space above the charge overheated with a wastage of fuel gas. If the level is too low, the lower part of the charge is overheated while waiting for the top to burn off, again with a waste of fuel gas.

The level of the top of the heating flues is determined by the shrinkage of the charge and this can only be obtained with certainty by running several charges of the coal through existing ovens made available by members of the coking industry. Once determined and built, the level of the flue top cannot be altered. The coal carbonised, however, may be changed and as charge shrinkage is related to volatile matter, sizing and water content, the flue level may be incorrect for the new conditions and fuel gas may be wasted.

It is therefore most necessary for the coal supplies for testing to be truly representative of what the plant when built will have to use, also for the plant owner to ensure that such coal is supplied as consistently as possible. If a change in the coal has for unavoidable reasons to be accepted, then it is worth while experimenting with the factors which are under the operators' control to obtain the same shrinkage as the original material.

It is argued that variations in charge shrinkage can be countered by the use of a compensating main to control the temperature of the free space over the charge. This is quite true and all difficulties of overheating this free space can be so avoided in this way. Nevertheless, if the level of the top of the heating flue is too high in relation to the coal being coked, this practice does not prevent the waste of fuel gas.

REGENERATORS

The correct design of coke-oven regenerators is a matter of considerable importance from the point of view of fuel economy. One of the present authors recently presented a paper[1] describing in detail the results of an experimental investigation into the factors governing the design of coke-oven regenerators. The work was undertaken because existing knowledge was incomplete or did not relate to the special conditions applicable to coke ovens.

In coke-oven practice the working draught is normally furnished by a chimney which provides a limited pull. In addition, as coke-oven regenerators are invariably built as an integral part of the oven battery, the pressure differentials must be kept low to avoid leakage through the brickwork. To achieve low pressure differences, gas velocities in the regenerators and flues must be kept low.

In view of the ready availability of processes for cleaning gases and the necessity for the prevention of dust deposition in any part of the oven heating system, the designer assumes the provision of clean fuel gas. Hence, on coke ovens, much narrower channels can be used in their regenerator fillings than in those of other furnaces.

The purpose of the investigation was :—

(1) To find the effect and quantitative value as regards heat transfer and pressure loss of the different factors in the design of staggered, straight through, or any other promising types of fillings. This would enable the effect of any variations in design to be calculated and would indicate the most profitable lines of development.

(2) Having found the best form of each of a number of different types of regenerator fillings, to compare their relative efficiencies on a practical basis to enable an economic assessment of the designs to be made.

Because of the complicated nature of the problem and the many factors which affect efficiency it was decided to build a full-scale test regenerator with all leading dimensions the same as in practice.

The effect on regenerator efficiency and heat transfer of the following factors were studied : rate of flow or load, size of regenerator, gas velocity, staggering of chequers, channel width, brick thickness, brick properties and length of reversal period. The influence of different designs of filling on pressure losses were also considered.

This is not the occasion to describe the work in detail, but, very briefly, it was shown experimentally that :—

(*a*) the surface area has so much more influence on the heat transfer than either the velocity or the efficiency of sweeping of the surface that in a given regenerator chamber a filling giving a large surface per cubic foot is considerably more efficient than any other arrangement ;

(*b*) staggered chequer bricks showed a small increase in the efficient use of the surface with a change from 4½-in. to 2-in. courses, but the number of bricks is much increased with consequent effect on cost. The velocity can be increased by closer spacing of the chequers, but the pressure loss will set a limit to this. The surface area can be slightly increased by the use of smaller bricks, but lack of stability prevents the use of bricks less than 1½-in. wide.

The practical outcome of this investigation is that the oven designer can now calculate the quantity of each type of filling required to give a desired regenerator efficiency. With this knowledge and with the current prices of different fillings it is possible to work out the most economical arrangement. A change in the relative prices of the different fillings may alter the choice of filling.

The importance of the size of the regenerator varies according to the type of fuel gas being used. With blast-furnace gas firing the bigger volume of waste gas makes it both more worth while and more necessary to provide bigger regenerators than with coke-oven gas firing. The following example shows that the effect of reduction of regenerator size is much more marked with blast-furnace gas firing, both as regards temperature of waste gas at the stack and percentage loss up the stack. If a battery of coke ovens designed with large regenerators gives a regenerator efficiency of 92 per cent., a stack loss of 15 per cent. and a stack temperature of 320° C. on coke-oven gas firing, then the same battery would give a regenerator efficiency of 85 per cent., a stack loss of 14·7 per cent. and a stack temperature of 250° C. on blast-furnace gas firing. On the other hand, if a battery of coke ovens designed with small regenerators gives a regenerator efficiency of 80 per cent., a stack loss of 22 per cent. and a stack temperature of 450° C. on coke-oven gas firing, then the same battery would give a regenerator efficiency of 67 per cent., a stack loss of 30 per cent. and a stack temperature of 470° C. on blast-furnace gas firing.

Losses of heat from the waste gases after the reversing valves, and air infiltration often result in a low recorded stack temperature which suggests a good efficiency. It is, however, entirely bad as the available draught is reduced and risk of corrosion of the castings and damage to brickwork is increased.

CONSTANCY OF OPERATING CONDITIONS

In the previous section of this contribution the authors have attempted to set out briefly the principles on which the designer works to provide an efficient plant. They would, however, underline the opinions of the Fuel Efficiency Committee set out in the first bulletin that the operation of a coke-oven plant at maximum efficiency can only be achieved if working conditions are as nearly uniform as possible. The charging of a coal mixture of uniform coking properties, constant grading and moisture contents has a profound influence on the operating efficiency of a battery as well as on its life. With such a starting point it is possible to adopt a regular pushing schedule. With regular coal quality and a regular pushing schedule it is possible to adjust the flue temperatures at the lowest figure consistent with the desired coke quality. The flue temperatures of a modern large oven cannot be adjusted to meet daily fluctuations in moisture content, bulk density or throughput of coal. Such fluctuations necessitate the temperatures being adjusted to suit the worst conditions, resulting in a waste of fuel gas at other times.

DISTRIBUTION OF HEAT

The Fuel Efficiency Committee in their first bulletin give detailed consideration to the question of heat losses from a coke-oven battery.

The heat supplied to the battery is expended in three directions :—

(1) In supplying heat for the actual carbonisation of the coal.

(2) In overcoming radiation and convection losses from the battery surface.

(3) In the waste gases passing up the chimney where the heat performs the useful function of providing the necessary draught for the combustion system.

HEAT EXPENDED IN THE OVEN

Provided that the ovens are designed in accordance with the principles outlined previously, that the plant is being properly operated and that the coal charge is uniform in its properties, then the quantity of heat used becomes a function of the type of coal carbonised.

Every designer knows that after making allowances for different moisture contents, coals vary in the amount of heat they need to convert them into coke. This makes the comparison of performance between plants of the same design working on different coals a difficult matter. Data on the subject is scanty. It would appear to be a fruitful field of research which the British Coke Research Association should consider.

The effect on the heating efficiency of an oven of the moisture, grading, ash and volatile matter is also very imperfectly understood. The authors are pleased to see that in the second Fuel Efficiency Bulletin the arbitrary correction of fuel consumption to conditions of dry coal which was given graphically in the first bulletin has been superseded and that it is now recommended that the correction be made to 8 per cent. moisture content, with no correction below this figure. The plant designer will carefully consider the implications of the data and curves given in this second bulletin. The authors would, however, suggest that Fig. 4, which shows the influence of the moisture content on carbonising rate, includes so many unknown and variable factors that further investigation seems desirable before the conclusions can be accepted as final. Such factors as wall thickness, " soaking " of the coke and so on would have to be eliminated in " control " tests.

The behaviour of the moisture in the coal during the coking process is not as simple as might be supposed and is a further field of research work which is commended for investigation. Water, as has been frequently demonstrated, is known to drain from coal more easily after charging, but the mechanism by which it does so is not fully understood. Much damage to coke ovens could be avoided if the relationship could be established between particle size and the percentage of water a coal would hold at charging temperatures. It is also probable that the type of coal has a bearing on its draining properties.

SURFACE HEAT LOSSES

In the first bulletin the radiation and convection losses are sub-divided under the main items of a battery as percentages of the total radiation and convection losses. The sub-division will vary according to the design of plant, but to keep the figures in perspective and to measure the possible influence on fuel consumption of any savings due to modifications in design, it may be of interest to group the losses in terms of B.Th.U. per lb. of coal :—

	B.Th.U./lb. Coal
Losses from doors and frames	20
Losses from oven steelwork (buckstays, etc.) . . .	40
Losses from battery top (including castings) . . .	57
Losses from regenerator walls and castings . . .	23
Total . . .	140

These figures show that the most promising field for reducing losses by radiation and convection lies in the direction of better insulation of oven tops and behind the side buckstays. The development of high-temperature insulating materials has enabled the plant designer in recent times to reduce the heat losses from both these items. Improvements in these directions should be profitable as well as being conducive to better working conditions.

COLLECTING MAIN REGULATION

The authors are pleased to note that the Fuel Efficiency Committee lay stress on the importance of maintaining a pressure of not less than 3 mm. in the collecting main. They agree that the deleterious effects of air admission to the ovens cannot be too highly emphasised and will give cause to numerous troubles especially in reducing the life of the battery structure. The first bulletin of the Fuel Efficiency Committee in which the above recommendation was made was dated January, 1944. It is interesting to record that the interim report of Panel 6 of the British Coke Research Association on Practical Plant Problems gave statistical data showing the influence of collecting main pressures on damage to buckstays, door frames and jamb brickwork and supported the earlier findings. This is a simple battery control item which should be followed throughout the country with advantage on many counts.

CONTROL INSTRUMENTS AS AN AID TO FUEL ECONOMY

The Fuel Efficiency Committee rightly emphasises the need for the provision of an adequate number of instruments on coke-oven plants as a means of securing fuel economy, but it should be stated that the installation of complicated and expensive instruments does not necessarily constitute scientific control of the coking process. Three essentials must be observed.

1. *Range of Instruments Provided.*—The bulletin publishes a list of instruments which the committee regard as the minimum necessary to give an accurate assessment of plant performance. These, at least, should be provided.
2. *Accuracy of Instruments.*—Unless the instruments are accurate their installation is not only a waste of money but will lead to wrong conclusions. Many large organisations have special departments for instrument maintenance, but the majority have not. In such cases it is a sound plan to arrange with the instrument makers for regular quarterly inspections by a proper instrument engineer. It is an advantage, in such circumstances, to have all the instruments of one make.
3. *Interpretation of Results.*—Charts and records are of little value unless their meaning is intelligently interpreted. Scientific control of plant working is impossible unless a competent staff is available to study results and draw proper conclusions from them.

TECHNICAL SUPERVISION

The authors stress the need for adequate technical supervision on the plant. It is not a costly matter having regard to the value of materials processed and the products made. For example, on a 1,000-ton per day battery the salary of one high-grade technical assistant would be more than covered if his work led to the saving of less than 1 per cent. of the fuel gas used on the battery.

The same reasoning may be used to show how undesirable it is to give the battery heaters other duties than the regulation of heats.

PLANT MAINTENANCE

A coke-oven plant cannot be operated at high efficiency for any long period without regular and systematic plant maintenance. It is the experience of the authors that the final responsibility for plant maintenance should lie with those directly interested in the performance of the plant. A high standard of maintenance is more easily achieved if a proper system is adopted of recording the condition of each part of the plant at regular intervals. At one plant known to the authors a thorough quarterly inspection is made and recorded for the whole plant, including a survey of each oven wall. A chart is provided for each wall, showing every brick. Defects revealed by the inspection are marked on the chart and the steps taken to deal with them. A continuous record of the history of each oven wall is therefore available over a period of years.

In addition, at this plant, units are laid off for inspection, adjustment and cleaning at specific intervals, whether they need it or not. All this may seem a great deal of trouble, but the results justify it. This particular plant, which is of modern design, has passed its sixteenth birthday and is still so good that no term can yet be set to its life.

PRODUCTION AND DISTRIBUTION OF STEAM

In the production and efficient use of steam, the coking industry lags behind in that it has not taken advantage of modern technique of steam generation or the peculiar possibilities a coke-oven plant as a whole offers in making striking reductions in steam consumption.

Few coking plants operate with a boiler pressure of over 140 lb. per sq. in., and while the practice of using exhaust steam for process work is fairly common, the overall steam consumption is rarely less than 400 lb. of steam per ton of coal carbonised and is often as high as 600 lb. on a complete plant. Provided the plant designer can fix the steam pressure and temperature for a new installation he can reduce the steam requirements to not much more than 200 lb. per ton of coal coked on a complete coke-oven plant.

The system in broad outline is as follows :—

(1) Steam is generated at the boilers at 350–400 lb. per sq. in. and is supplied only to the exhauster turbines.

(2) The exhauster turbines exhaust against a back pressure of, say, 120 lb. per sq. in., which forms the intermediate-pressure line for steam supply to pumps, oil heaters, rectification stills, etc.

(3) The liquor circulating pumps are turbine driven. They draw steam from the 120 lb. medium-pressure line and exhaust into the low-pressure main at, say, 25 lb. per sq. in., from which process steam is drawn for ammonia and benzole stills.

It is evident that provided the pressure and temperature of the high-pressure steam supply is carefully selected, and the intermediate pressure properly calculated, the whole of the steam requirements of the plant are met by the steam fed to the exhauster turbines.

The steam pressure required at the boilers varies somewhat according to circumstances, but usually does not exceed 375 lb. per sq. in. This pressure is much below what power station practice has been for years.

The only opportunity British constructors have had in applying this principle relates to installations built overseas.

Discussion

Mr. T. W. Mills said that he had installed a coal dryer and in consequence had obtained a 5 per cent. increase in coke output and had been able to send 15 per cent. more gas to the gas undertaking that he was supplying. Much more fuel could be saved if deliveries of new plant could be made more quickly. The domestic fuel position could be eased somewhat if coke nuts were intelligently mixed with coal.

Mr. Curry said that heat losses from oven tops were still too great, the insulation provided being inadequate. The further insulation of coke ovens would enable greater supplies of gas to be supplied to public utilities.

Mr. H. J. Victory wrote : Time did not permit my raising the following point regarding instrumentation of ovens during the discussion at the conference.

A minimum list of the instruments for coke-oven plants is suggested in Fuel Efficiency Bulletin No. 1 (p. 2) and stress is rightly laid upon the importance of the gas meters and upon proper control and checking of instruments. In their paper Messrs. Barritt and Finlayson again emphasised the importance of accuracy and proper use of instruments.

Many, if not most, of the gas meters installed at coke ovens are today of the orifice plate type. It is probable that in practice (providing always that proper attention is paid to cleanliness and mechanical maintenance) no other single factor affects the accuracy of the inferential type of gas meter as greatly as variations in the specific gravity of the gas from that for which the meter is calibrated. Even if a meter is calibrated for the actual specific gravity of the gas made when the meter is first installed it is possible, at any rate where rate of output and nature of coal carbonised are subject to considerable variation, for the specific gravity of the gas to vary so widely in the course of a few months working as to cause errors varying up to 6 or 7 per cent. in the metered volume of gas. Such conditions probably apply rather to coke-oven plants forming an integral part of a composite steelworks than to merchant plants, but even so, I do not think this source of error is as widely appreciated as it might be. In view of the important effect that specific gravity of gas can have upon the accuracy of inferential meters I feel that it would be well worth recommending inclusion of an instrument permitting quick determination of specific gravity of gas (e.g. of the George or Bunsen type) in the minimum list of suggested instruments.

Further, I am not sure that it is altogether wise to press for installation of integrators on recording gas meters. It has been my experience that the integrator is the most troublesome part of the inferential meter to maintain. Without an integrator the meter mechanism is simple to service and one can take gas totals easily from recorder charts by use of a suitable planimeter. Where it is necessary to correct the reading of an inferential meter to take into account variable qualities (e.g. temperature or specific gravity of the gas) I believe there is less likelihood of error in the correction calculations when the chart-planimetering method of assessing total gas volumes is adopted.

Mr. W. T. Summers wrote : The proposed method of measuring the efficiency of a coke-oven battery appears to have much to recommend its widespread adoption for the internal checking of the efficiency of heating. It would be of considerable interest if the results obtained at one or more plants could be given either completely or as a mean figure, together with the variance.

Does the value of η vary systematically with the throughput of the battery ? Why have the authors not devised an equation which contains a term, for example, relating the output of gas from the battery to the quantity of gas used to sustain that output ? The numerical value of η appears to be a measure of the efficiency of combustion of the fuel gas ; but does it measure the efficiency with which the heat of combustion is utilised ? Is it not possible, for instance, to secure " efficient " combustion, though the chamber temperature distribution is not satisfactory ? Is the degree of maladjustment reflected in the value of η ? Is there any evidence to show the extent to which thermal efficiency of combustion is related to such factors as relative height of flues to coal charge, shrinkage of coal charge, free carbon in the tar ?

The results of six months' operation of a centrifugal dryer confirm the figures for the influence of moisture reported in Coke Oven Bulletin No. 2. The coal treated is below 1-in. (containing 80 per cent. below ½-in.) with an air-dry moisture content of 6·0 per cent. at 66·0 per cent. relative humidity. The oven charge now contains 8·5 per cent. H_2O (previously 12·0 per cent.) and the flue temperatures are 1330° C. (1370° C.). Additional gas required over underfiring requirements is 520 cu. ft. per ton. The advantage of the absence of " drainable water " is that the flexibility of coal crushing is enhanced, as it is no longer necessary to grind finely in order to prevent drainage of water in the ovens ; the degree of grinding can now be related to other requirements.

Exception may be taken to the expression on page 8 of the bulletin for " losses of coal in the effluent ". The effluent should be treated to recover the finely divided material which will have an ash content comparable with the " dry pit dust " and which can be up-graded and returned to the coking slack, or (if sufficiently clean not to require upgrading) recovered by flocculation and filtration. The cost of recovering the coal from the effluent is not properly chargeable against the centrifuge plant, as any wet washer should have available proper means of adequately dealing with its particular grade of slurry.

Turning to the paper by Messrs. Barritt and Finlayson, I would ask the authors to develop some of the points cursorily treated of necessity.

Does the " correct level " of the top of the heating flue bear any fixed relation to the initial height of the charge or the final height of the product ? The former height in a given oven is sensibly the same, but the latter is variable, depending (at least for one class of coal) on grading, and perhaps on moisture content, rate of heating, etc. For domestic cokes, the " economic " coal grading can hardly be fixed from small scale tests, but must be found by trial after the battery is operating ; the choice of " correct level " of the heating flue is therefore problematical. The only controllable variable is the height of the coal ; if the " correct level " of the heating flue is of such importance, will flexibility in the height of the levelled coal charge assist when the conditions for which the battery was designed no longer obtain ?

Does a double collecting main prevent the gas pressure at the bottom of an oven rising to the same figures as with a single collecting main ?

The note on steam requires reconciliation with the various fuel efficiency bulletins ; whereas the authors advocate increasing the steam pressure, the bulletins recommend using the lowest possible pressures for power and process duties ; the thermodynamical argument cannot be gainsaid. The advocates of higher pressures do achieve a saving in steam ; it is of importance to ascertain both the capital costs and the running costs of, say, the system described by the authors and of a lower pressure plant using, for example, vacuum benzol plant.

A system which reduces the steam consumption by one-third is very attractive and the possibility justifies elaborate investigation.

Mr. F. H. Metcalf, replying to Mr. Summers, wrote : Insufficient data are available at the moment to give much information regarding the results obtainable throughout the country. It would appear from preliminary work that efficiencies vary between about 60 and 80 per cent. at different plants.

The value of η is a measure of the efficiency of combustion of the fuel gas and though the maximum attainable efficiency at a given plant may be associated with such factors as Mr. Summers suggests, it would require an immense amount of work to determine these relationships.

It would be possible to secure " efficient " combustion together with poor chamber temperature distribution but that is largely a question of design and this method was never intended as the only control instrument in the hand of the coke-oven operator but rather as an added control in addition to those already applied by him such as temperature distribution in the flues, etc.

Mr. D. T. Barritt and **Mr. T. C. Finlayson** wrote : We wish to reply to points raised by Mr. Summers as follows :—

(1) The level of the heating flue top is not determined by the initial height of the coal charge but solely by the level of the finished coke. We know of no small-scale test which will give the finished coke level at all accurately, although we have made repeated efforts to find one. The only safe method is to run several charges of the coal through an oven approximating in size and working conditions to that proposed and to take the actual shrinkage measurements.

These measurements, of course, apply to one coal only and to one grading. If either or both are altered, the shrinkage may, and probably will, change to the extent of making the position of the flue as built entirely unsuitable. For this reason we stress in the paper the desirability of not altering the coal or its grading from the sample tested.

If the coal has unavoidably to be altered after the plant is built, it is possible to adjust the setting of the leveller bar up or down and so alter the finished coke level. This adjustment is usually rather limited, however, and is rarely more than ± 3-in. from the mean position. Alternatively, if the shrinkage with the new coal is greater than with the original, making the flue level too high, the compensating main can be used successfully to correct overheating of the free space above the charge. As we explained in the paper, this leads to some waste of fuel gas.

What is needed, of course, is some method of altering the heating flue level at will to take care of variations in coals used. Until this desirable but extremely elusive design is found, we repeat that the coal for which the plant was designed should not be changed without full appreciation of the possible consequences.

(2) With large ovens working at fast rates on dry coal, the ascension pipe and valve often restrict the flow of gas in the early stages of coking and give rise to unduly high pressures in the chamber. Double ascension pipes will cure this fault. A recent test carried out on 18-in. ovens fitted with dual mains and coking dry Durham coals on a 16-hour schedule showed :—

(*a*) A pressure in the free space of never more than 2·5 mm. w.g. at any time.

(*b*) A pressure of about 1·5 mm. in the free space at the end of the coking time.

(*c*) A pressure of ± 0 mm. w.g. at the base of the oven and against the walls at all times throughout the coking cycle.

To achieve (*c*) the liquor-sealed ascension pipe valve was notched back progressively after about the fourth hour. The pressure in the collecting main was constant at 4 mm. w.g.

(3) The remarks on steam usage require qualification. An average coking plant rarely uses more than 20,000 lb. of steam an hour. If the coking plant is a separate entity and has perforce to raise its own steam, this load would be met adequately by, say, four Lancashire boilers or a small water-tube boiler working at 120–160 lb. per sq. in. It would be uneconomical to build high-pressure boilers for so small a load. If, on the other hand, the coke ovens are part of a steelworks or colliery where the total steam demand is high, water-tube high-pressure boilers show substantial economies on the works as a whole and in particular on the coke ovens if the system we suggest is adopted.

The fuel efficiency bulletins rightly lay stress on methods of avoiding steam wastage and these are of great importance. The savings they effect, however, are dwarfed by the striking savings it is possible to effect by a well-balanced steam system such as we describe. Fuel efficiency bulletins emphasise the importance of generating steam at high pressures when it can be used for power generation in back-pressure sets, the exhaust steam being used for power. The subject is a large one and we suggest that the coking industry would benefit by a paper on the subject by a steam engineer accustomed to coke-oven and steelworks practice.

Mr. G. W. J. Bradley, replying to Mr. Summers, wrote : I agree with the comments made by Mr. Summers. Whether fines recovered from the centrifuge effluent should be added back to the coking coal will depend on local circumstances. I certainly agree that this should not be charged against coal drying.

Reference

[1] J. Inst. Fuel, February, 1946. T. C. Finlayson and A. Taylor : " An Experimental Determination of the Factors Governing the Design of Regenerators with Special Reference to Coke Ovens."

SECTION E. THE CARBONISATION AND CHEMICAL INDUSTRIES—*continued*

SESSION III. The Chemical Industries

Chairman of Session: MR. L. P. O'BRIEN
CHAIRMAN OF THE ASSOCIATION OF BRITISH CHEMICAL MANUFACTURERS

THE CHAIRMAN asked Dr. Dunningham to make a general statement on the efficient use of fuel in the chemical industries.

Dr. Dunningham pointed out that the chemical industry consisted of many branches having widely different problems, some producing large quantities of relatively cheap products and others small quantities of expensive products. In some sections of the chemical industry, fuel efficiency had been practised to a very high degree, as, for instance, in alkali manufacture, where every stray therm was pursued with relentless vigour. In other sections there was yet much to be done, probably because in the past fuel had only formed a small item of the total cost of manufacture.

The task of the chemical industry was to provide the means whereby chemical reactions might be carried out on an industrial scale. This involved two processes. First, the chemist must investigate his reactions and lay down the conditions under which they must be carried out ; second, the engineer had to provide the plant required for this purpose and to generate and apply the necessary heat. Fuel efficiency could, therefore, be considered as consisting of two parts. In the first place, the chemist must re-examine his reactions in order to determine whether they can be modified or carried out in a different way so as to lessen the heat requirements. The engineer must then consider whether he can generate and apply the necessary heat more efficiently.

The first step was a careful thermal analysis of the process as a whole with the production of a heat flow (or " Sankey ") diagram showing as exactly as possible where the heat went. It was often necessary for this analysis of a single process to be considered in conjunction with a similar analysis for the works as a whole, because the saving of heat in one process might involve its usage in another and the power/steam balance of a works would determine the form of energy which should be utilised in a particular process.

A number of general lines of attack upon the problem of fuel efficiency was given in the papers submitted to the session, and Dr. Dunningham devoted most of his introductory remarks to giving the following specific instances of the application of the two steps he had mentioned and to indicating some promising lines for future investigations :—

Modification of processes and operating methods

(1) In a water-gas plant the process was modified in such a way as to make possible the collection and utilisation of part of the blow gas with a saving of more than 30,000 tons of coke a year.

(2) A catalytic gaseous reaction carried out in a number of reaction vessels was formerly concentrated in the smallest possible number of such vessels. It was found, however, that by using all the available plant the space velocity was reduced and the reaction made more efficient. There

was a consequent saving in steam, which was one of the reacting gases, equivalent to 8,000 tons of coal a year.

(3) In another catalytic reaction an improved catalyst was found which made less frequent shut-downs necessary and economised heat equivalent to 600 tons of coal a year.

(4) In still another process, the reaction was modified in such a way as to reach the end product with a smaller expenditure of heat, the total saving being equivalent to 1,800 tons of coal a year.

(5) In a certain process an ore was digested with sulphuric acid, the vats being heated by the direct addition of live steam. This digestion occupied 48 hours but it was found that by increasing the steam supply this period could be reduced to 24 hours. Although the hourly consumption of steam was increased, the total for the whole digestion process was very much reduced.

(6) In an organic reaction usually carried out at 0° C. it was found possible with suitable precautions to obtain equally good results at atmospheric temperature. This resulted in a considerable saving of ice and hence of fuel.

Engineering

Ignoring waste-heat recovery, which is mentioned in the papers, the following suggestions were made for promising lines of further work.

(1) The power/steam balance of the works should be carefully considered with a view to using pass-out steam derived from power generation for process and heating purposes. Where the balance was not sufficiently close every endeavour should be made to run in parallel with the national grid.

(2) The possible substitution of mechanical solid-fuel firing for producer gas should receive careful consideration. Producer gas is usually chosen because of ease of control of combustion and of atmosphere and also because intense local heating resulting in damage to plant can be avoided. Such conditions cannot be obtained with hand firing but it is now being found that sufficiently good control of combustion conditions may be obtained with solid-fuel firing resulting in cheaper heat.

(3) Steam should be re-compressed where possible and where it fits in with the thermal balance of the works as a whole. The temperature of the steam is thereby raised by the application of mechanical energy derived from high-pressure steam or electric power. The value of such a process, therefore, obviously depends upon the relative availability in the works of power and of high and low pressure steam. Re-compression has been practised for a number of years on the Continent in connection with many processes involving evaporation and it is also being used successfully in this country.

(4) The use of special heat and/or acid-resisting metals for recuperators, economisers and other waste-heat recovery plant may well be worth consideration, because the use of such materials avoids the necessity of keeping above the dewpoint. Use of such materials may make it possible to recover much more heat from boiler flue gases and other gaseous products of the chemical industry.

(5) The La Mont system of waste-heat recovery as developed in Sweden, where shortage of fuel has led to intensive efforts to improve

fuel efficiency, may find application in many chemical processes where small and scattered units, often working intermittently, are used. A large number of small heat-recovery units may thus be connected to one common boiler drum.

Whilst most of the economies hitherto realised had been due to the better application of well-recognised means for preventing heat loss, such as insulation and condensate recovery, Dr. Dunningham believed that a much wider field for fuel economy was being opened by fundamental investigation of processes on such lines as he had outlined. Such investigations had already proved very fruitful in his own company (Imperial Chemical Industries, Ltd.).

1. Fuel Efficiency in the Chemical Industry

By A. C. DUNNINGHAM, D.SC., F.INST.F.

The essential task of the chemical industry is to provide conditions under which chemical reactions can take place on an industrial scale. The chemist investigates the reactions in the laboratory and lays down the conditions, such as temperature and pressure, which must be observed for successful operation. The transition from laboratory to works involves many problems including those of constructional materials and very often leads to compromises between the chemist and engineer. When a chemical plant has been brought into successful operation there is a natural tendency to stereotype the process and let well alone, but it should always be recognised that modifications may be possible which would result in economy in steam, power and other services tending directly or indirectly to economy of fuel. It may well be that such economies would have been economically negligible in the days of cheap fuel but under present-day conditions it is essential that all processes, however well established, shall be most carefully reviewed and in doing this the closest possible co-operation between chemist and engineer is necessary. As a first step a thermal analysis of the process should be made which can often be conveniently expressed in the form of a Sankey diagram. This indicates the field available for economy. It will usually be found that only a small part of the heat applied to the plant is actually required for the reaction which in some cases may even be exothermic. Amongst many process modifications which may be possible the following may be noted :—

(*a*) The chemical route between the raw materials and final product may be altered so as to reduce " service " requirements.

(*b*) The methods adopted for following this chemical route may be modified. As an example, it may be possible to use purely physical means, such as filtration, for separating two substances where at present some such process as steam distillation is used.

(*c*) The temperature range within which the reactions are carried out may be modified. Thus it may be possible to substitute atmospheric temperature for high or low temperatures hitherto considered necessary.

(*d*) Heat requirements may be reduced by modifying the method of application. Thus large batches may be substituted for small or it may be possible to use a continuous process. Considerations other than those of engineering may be involved because the method and rate of heat transference may affect the chemical reaction.

(*e*) Requirements as regards fine grinding or intimacy of mixing may be modified with resultant saving of power.

(*f*) Mechanical stirring may be substituted for agitation by means of steam or compressed air. In this connection it is often found advantageous to replace line shafting by unit drives.

(*g*) Precautions against contamination may be relaxed or means devised for counteracting the effects. It may then be possible to adopt a cheaper method of heating as, for instance, the substitution of direct coal for producer-gas firing.

(*h*) The latent heat of reject process steam may be utilised as, for instance, by the adoption of multiple evaporation, the use of partial condensers to preheat feed to stills and evaporators and the withdrawal of vapours from evaporators for sensible heating. The heat lost in reflux distillation may also be recovered. Increased attention is being given at the present time to steam re-compression by which means substantial savings may be obtained. In one case such savings exceeded those which could be obtained by converting a batch process into a continuous one and thus rendered unnecessary considerable capital expenditure.

(*j*) The adoption of counter-current methods in solvent extraction and washing processes may often lead to a considerable reduction in the heat required for subsequent re-concentration. Such methods may be either batch or continuous. Examples include the leaching of sugar from beet and of tannins from barks. Filter presses can often be washed in a counter-current manner by using dilute washings from one batch as the first wash liquor for a subsequent batch.

Investigations into such possibilities as those mentioned above are being made in the company to which I am attached, sometimes with remarkable results. The field for such work is almost unlimited especially when we realise how little of the heat actually applied is in many cases theoretically required by the reaction.

Apart from the possibilities latent in fundamental investigations such as those suggested above there is little to distinguish between the principles of fuel economy in the chemical and in other industries. The prevention of unnecessary heat losses by means of insulation and similar methods requires no special consideration here, except to remark that the work of the Fuel Efficiency Committees set up by the Association of British Chemical Manufacturers has done much to secure the general application of these in chemical works. Waste-heat recovery, however, presents some special problems which may be considered briefly.

The sources of waste heat in the chemical industry may be divided broadly into three categories—

(*a*) hot gases ;
(*b*) hot solids ;
(*c*) hot liquids.

HOT GASES

The problems involved in the recovery of waste heat from hot gas in the chemical industry are very similar to those encountered elsewhere and usually involve some form of waste-heat boiler, economiser or air heater either separately or in combination, unless it is possible to use recuperators or regenerators and so return the heat to the process and directly increase its efficiency. Apart, however, from the normal problems involved, other difficulties often have to be taken into consideration such as :—

(*a*) Corrosive properties of the gas.
(*b*) Excessive dust content of the gas.
(*c*) Intermittent working of the plant.
(*d*) Small and scattered plant units.
(*e*) Lack of effective demand for the recovered heat.

We will now consider these separately.

(*a*) CORROSIVE PROPERTIES OF THE GAS

Where ordinary products of combustion are concerned, the application of waste-heat boilers, economisers or air heaters is quite a normal proposition and depends upon the size and continuity of operation of the plant and upon the use to which the steam, hot water or hot air so produced can be put. This also applies to certain products of chemical reactions such as the combustion of sulphur as a preliminary to the preparation of sulphuric acid. These gases, being dry, can be passed through a normal heat-recovery plant without deleterious effects and can often be used to raise all or part of the steam necessary for the running of the process. The gases produced, however, by the combustion of pyrites, although not corrosive, usually carry too much dust and lead to the blockage of the waste-heat recovery plant.

In salt cake manufacture and other processes waste-heat recovery depends on the type of furnace used. Where the products of combustion pass directly over the charge they carry away with them hydrochloric acid which is highly corrosive. On the other hand when closed muffle furnaces are used contamination of the gases in this way does not occur and normal waste-heat recovery can be practised. Many other processes will no doubt come to mind in which similar problems arise. It is, of course, essential that the temperature of the boiler exit gas shall be above the dewpoint, but the use of acid-resisting steel for heat-recovery plant may overcome this difficulty.

(*b*) DUST CONTENT OF GASES

A case has already been mentioned above in which excessive dust content has so far made waste-heat recovery difficult or impossible. Similar difficulties arise in cement kilns, the gases from which are heavily laden with dust. As far as is known no waste-heat boiler has been successfully installed behind such a kiln in this country, but references in literature suggest that it has been done in Australia and it is said to be common practice on the Continent.

(*c*) INTERMITTENT WORKING OF THE PLANT

Many batch processes which work at high temperatures are intermittent and are therefore very difficult to link up with waste-heat recovery boilers. Often, however, it is possible to equip such plant with recuperators or regenerators, in which case the recovery of waste heat and its utilisation in the process must always synchronise. High-temperature plant should always be designed with this possibility in view and indeed this may be essential in order to obtain the required temperature. An instance of this is provided by plant fired by producer gas, such as many metal treatment furnaces, glass furnaces and other high-temperature plant. The difficulties of intermittent operation can sometimes be overcome when the working of a number of plant units can be staggered so that the overall average waste heat available for recovery remains more or less steady, but there is no doubt that it frequently presents a very serious difficulty.

(*d*) SMALL AND SCATTERED PLANT UNITS

Many chemical processes involving high temperatures are of necessity carried out on a small scale which makes recovery of waste heat exceedingly difficult, particularly when these plants are scattered. It is stated, however, that in Sweden adaptation of the principle of the La Mont boiler has made possible the recovery of small quantities of heat from very scattered localities and its concentration in a common boiler drum. This is probably worth further investigation in this country. A case may be quoted in which a number of plant units discharge flue gas at approximately 700° C. into a common flue leading to a waste-heat boiler. The heat losses occurring in this flue from leakage and other causes might be largely avoided if each plant unit were equipped with its own La Mont unit connected with a common boiler drum.

(*e*) DEMAND FOR WASTE HEAT

It often happens that a proposal for the recovery of waste heat is negatived because no effective application of this heat is apparent. Much low-grade heat, however, is often required for space heating and hot water supplies and in many works relatively low-temperature drying processes at present separately fired could equally well utilise low-grade heat. All these possibilities can be taken into account in designing a new works, but they are often very difficult to apply in an old one. Independent economisers or air heaters linked up with a secondary system of heat utilisation may sometimes be installed in flues.

Many chemical works generate high-pressure steam which they pass through turbo-generators before using for process and heating purposes and it is important that the balance between steam and power requirements shall not be upset by the generation of steam from waste heat.

HOT SOLIDS

Solid materials produced at high temperatures often carry considerable waste heat which can sometimes be recovered by preheating the air for combustion or by other means. On the other hand, the solid raw material may itself be preheated by the outgoing gases. The modern vertical lime kiln affords an example of both these processes. The high temperature reaction takes place near the middle of the kiln and the hot lime passing downwards is cooled by and preheats the incoming air, whilst the cold limestone in the upper part of the kiln is preheated by the products of combustion and high efficiencies are obtained. A similar effect can be secured in properly designed rotary kilns and in tunnel kilns. As another example of heat recovery from solid material the dry quenching of coke may be mentioned. This has not been largely adopted up to the present owing to its doubtful economic value, but in the light of present-day fuel prices the proposition is now undoubtedly worth very careful reconsideration.

HOT LIQUIDS

Recovery of waste heat from *hot liquids* is widely practised by means of heat interchangers and there is little doubt that the careful re-examination of many chemical processes would suggest other means of heat recovery.

In dealing very briefly with the special problems connected with waste-heat recovery in the chemical industry I have of necessity said little about the normal processes which, in a well-designed works, are a matter of every-day application. Waste-heat boilers are frequently installed behind roasting and concentrating plants and it is now proposed, where the waste gases are at 600° C. or more, that consideration should be given to the installation of an economiser behind the waste-heat boiler. If the water/gas ratio is not satisfactory, a secondary economiser system may be possible. Waste-heat recovery in such processes is a very important economic factor and is often practised to the highest degree.

Considerable economies are now being envisaged by the substitution of solid fuel for producer-gas firing. The latter is often specified in order to obtain uniform temperature conditions and efficient control of atmosphere. The use of mechanical stokers instead of hand firing, however, often enables these conditions to be realised with solid fuel, and equal efficiency of combustion is also obtainable. Under present conditions a therm in the form of producer gas may cost from 1½ to 2½ times the cost of a therm in coal from which it is made, so that there is obviously every economic incentive to eliminate producer-gas firing whenever possible. If, as may sometimes be the case, the use of cold clean producer gas is essential, the question of the recovery of sensible heat by means of recuperators should be considered. This should not present any insuperable difficulties with tar-free gas from anthracite or coke and there are indications that suitable metal recuperators either calorised or made of special steels are becoming available. This is a question which should be thoroughly investigated.

In conclusion it may again be emphasised that a thorough examination of all processes should be made in the light of present-day conditions and consideration or reconsideration be given to all possible proposals for waste-heat recovery in any of its forms. When the known low thermal efficiencies of many processes are considered, it is evident that a very fruitful field of economy still remains to be explored.

Discussion

Mr. Sedon Brundit believed that much fuel could be saved in the chemical industry, for example by such simple methods as good layout of steam traps, installing heat exchangers, flash tanks, etc. There must be co-operation between engineers, chemists and plant managers, with full investigation of all problems. Particular attention should be given to process timing with the object of reducing peak loads.

2. Design of Chemical Works
Fuel Economy Related to Other Factors in Design

By B. E. A. VIGERS, B.A. (CANTAB.), A.M.I.C.E., M.I.CHEM.E.

A paper on the design of chemical works cannot ignore the fact that its subject involves a complex function of inter-related variables of which fuel economy is only one, and one which cannot be properly studied unless in relation to the others. The main factors which should be considered may be listed as follows :—

(*a*) The requirements and limitations of the process which is to be operated.
(*b*) The economy of energy in all its forms.
(*c*) The economy of water for cooling and process purposes.
(*d*) Economy in handling materials.
(*e*) The economy of labour, skilled and unskilled.
(*f*) The economy of capital, management and supervision.

The central thesis of this paper is to emphasise that in the design of works, unless due consideration and weight is given to all these factors from the outset, the greatest overall economy will not be achieved. Too often, the layout of a factory is determined on purely process considerations alone, the other points being regarded as services only, to be fitted in as well as may be, at a later date.

It is sometimes said that because the business of a company is the manufacture of certain products in which the services do not appear as a major item of cost, these services should be kept as simple as possible rather than striving after the highest economy; but although simplicity is always attractive, it can be misleading.

The intention is not to belittle simplicity as such ; it is agreed that if two solutions of a problem achieve the desired end, equally successfully in all respects, then the simpler solution is the better, but the aim of this paper is rather to invite further consideration from those responsible for the design of works who, for example, prefer to instal low-pressure boiler plant for process steam, and to buy all their power from the supply authorities on the grounds that any economy attained by combined generation is not worth the extra complication and maintenance involved. Such a view may be correct in some few instances, but it should not be so in general if enough attention is given to design, and if care is taken to conform to the principles which are dealt with in this paper.

In view of the foreseeable prospects facing the industries of this country, it is maintained that if the savings of a fuel economy scheme, such as that of the combined generation of heat and power, can be reliably shown to cover all its costs, howsoever arising, even though with little profit to the undertaking concerned, it should be adopted as a matter of national duty in order to save the coal which would otherwise have been consumed at the power supply authority's generating station. The engineer and management should be prepared to accept the extra responsibility which may be involved as a contribution to national economy and an aid to the continued operation of industry.

By the same token, an undertaking which does make such a contribution, is surely entitled to consideration from the authorities who are responsible for the allocation of fuel. In the example quoted there will be a saving of an amount of fuel at the supply authority's power station, but a fraction of this amount will be required to be burnt under the boilers of the factory in addition to that which would be required for low-pressure heating steam alone. This fact should be recognised, and the fuel should be made available.

The power supply authority should also play its part and be more ready than is often the case to allow paralleling of factory generating plants on their mains, if the necessary protective gear is provided.

Chemical works vary so widely in their requirements that it is quite impossible in this paper to cover individual cases. It is therefore proposed to consider the inter-relation of the various factors in the design of new works only, but with the hope that some of the points raised may also prove fruitful in the modernisation of old works.

It is not to be expected that the requirements of all the factors can be met to perfection. Some will have to be sacrificed in some measure in the interests of the others, but as has been said before, the best all-round result can only be attained if all are given consideration from the outset. Each will be dealt with in turn, and attention will be drawn to the points at which each impinges on the others.

ENERGY ECONOMY

If the principle is accepted that the designer of a process works is in duty bound to try to achieve the greatest possible overall economy in fuel, he must, at all times, pay close attention to the thermo-dynamic criterion that, whenever energy must be degraded, the maximum benefit resulting from the process must be striven for. Heat should be taken into the process at the highest practicable temperature ; thereafter, it should be used with progressively falling temperatures with the minimum of irreversible processes, and should finally be rejected at as low a temperature as may be.

A very common breach of this rule is the use of direct firing for drying processes, which could equally well be effected by means of low-grade heat, either in the form of waste gases from furnaces which have to be operated at high temperature, or more commonly by exhaust steam from engines. In both of the latter cases, the heat which is produced at high temperature by burning fuel is first used to perform a useful function before passing on with little loss of capacity to evaporate moisture in the dryer.

In those processes which involve high-temperature furnacing operations, the temperature required by the latter will usually dictate the conditions of the first use of the heat. It should, of course, be universally accepted that, wherever possible, the waste heat from such furnaces should be recovered in regenerators or recuperators, and the waste gases then passed to waste-heat boilers or other means of heat recovery.

Electrical furnacing operations are a special case in so far as the power supply, if obtained from thermal stations, has already passed through the process of conversion from heat to power. Except in such cases as the reduction of alumina to aluminium, where electric energy is used electrolytically as well as in the production of heat, or in the case of operations at extremely high temperatures, which could not be easily attained by other means, the use of such high-grade energy as electric power for heating should only be justified by very special process conditions or by exceptional economy of some other commodity such as labour or capital.

In the majority of processes where the major part of the heat required is not employed in high-temperature furnaces, the most usual method of application of heat is by means of steam. Applying the thermo-dynamic criterion, the steam should be generated at the highest practicable pressure and temperature. It should be first used for the generation of power in steam engines or turbines and exhausted at the lowest permissible temperature and pressure for process uses. The practical limit for the inlet temperature and pressure will be determined by the considerations of the size of plant involved and of capital, labour and management. Small engines and turbines are not available for very high pressures, owing to clearance losses, etc. A higher grade of management and operative labour is required for the successful operation of high-pressure plant, and while justified for a large output, the extra cost of such supervision would nullify the gain on a smaller installation.

Questions of the quality of water available as boiler feed and the amount of condensate which could be returned to the boilers also have a bearing on this subject.

High-pressure plant is, of course, more costly than low-pressure equipment of the same capacity, and if it is considered that availability is adversely affected, more provision must be made for standby, since overall reliability in the maintenance of output is usually of prime importance. For these reasons, high pressure usually involves high capital charges, but so long as all the foregoing factors are carefully assessed, the aim of the designer should be to justify and adopt conditions for the maximum generation of power.

It is not easy to determine the lowest pressure at which the steam can be exhausted. The stated requirements for process use should be subjected to close scrutiny. In a great number of cases, such figures are based on heat transfer requirements, and an examination should be made into the possibility of reducing the required temperature and pressure by increase of the area of heat transfer surfaces.

In chemical processes advance in this direction is sometimes restrained by the need for special and costly corrosion-resisting materials in the construction of such surfaces. The point is, however, so important that investigation should be made of the possibility of modifying the process to remove the difficulty. For example, film coefficient may be improved by reducing the viscosity of a liquor or by increasing its velocity; or again, it may be possible to avoid a difficult evaporation of an acid liquor by carrying out the necessary concentration at another stage of the process where the liquor is neutral. An alternative method of attack may be to supply the major portion of the heat required in a process by means of low-pressure steam, and thereafter to use a small quantity at a higher pressure in order to attain the final temperature which is required. Such methods of " stage heating " are good examples of the thermo-dynamic approach to heat economy problems and the regenerative feed heating methods which are adopted in high efficiency power stations would repay study by those who are not familiar with them.

Apart from the limitations of process requirements, the capital cost and heat loss from large low-pressure mains may be a deciding factor, and this is one of the most important aspects from which the layout of the works should be considered in relation to fuel economy.

A difficult case is that in which, while a majority of the factory requirements can be met at a low pressure, a certain amount of steam must be supplied at an intermediate pressure. In such cases, it is necessary to consider whether it is most economical (*a*) to raise the back pressure of the whole steam output to meet the higher requirements, (*b*) to degrade the necessary quantity of high-pressure steam to the intermediate pressure without recovery of power, or (*c*) to employ a pass-out machine to provide the necessary intermediate supply. The correct solution can only be determined by detailed investigation of the overall economics of each method.

Whilst the principal gain accruing to the use of process steam at a low pressure is that more power may be generated per lb. of steam used, there is an additional reason for keeping the pressure as low as possible. When the condensate is drained through traps from any appliance operating at above atmospheric pressure, the sensible heat above 100° C. will cause a proportion of the condensate to evaporate as flash steam, and this if allowed to escape to atmosphere represents an important loss. If the working pressure is low, this loss is minimised and may avoid the need for complicated arrangements for its recovery. If, however, the pressure must be high, it is most important that steps should be taken for such recovery, usually by allowing the condensate to flash in one or more stages into appropriate lower pressure users. If such an arrangement must be adopted, it will be facilitated if early consideration has been given to the layout of the plant so that successive users of the steam are conveniently adjacent to one another.

The grouping of plant in a factory in such a way that heat exhausted from one process either as steam or waste gases may be passed on efficiently to other users is a similar problem to that of handling materials through the factory, but it is often neglected.

The ideal arrangement is that the boilerhouse should be at the centre of gravity of the load. The engine house will normally be built alongside the boilerhouse, and it is desirable that big users of low-pressure steam should be situated nearby in order to reduce the capital cost and heat losses of the low-pressure mains. Users which must be supplied with high-pressure steam may be situated at a greater distance since the steam mains for the conveyance of a given quantity of steam at high pressure will be smaller than those required for low pressure, and pressure drop in the high-pressure mains is less important. Exhaust steam from the high pressure users should be discharged to an efficient flash system and returned via intermediate or low-pressure users towards the boilerhouse.

It is sometimes said that pressure drop in steam mains is of little importance since in itself it causes no loss of heat, and little fall in temperature. To take such a view is to sin against the second law, since the loss of pressure implies an increase of entropy and it is evident that anyone who maintains this view is thinking only in terms of the economy of heat and is taking no account of energy potential. The loss would be evident if all endeavours were being made to achieve the lowest possible back pressure on a steam engine or turbine. If no engine is installed, schemes ought to be in hand to put one in.

Heavy peak loads are amongst the most serious offenders against economy whether it be for steam, power or even water. As against an equivalent steady load, capital is increased by the need for bigger boilers, engines, mains, valves, switchgear, etc. Peak loads upset the efficient working of boilers and engines and usually additional labour and more careful management is required if waste is to be avoided. For these reasons, there is general preference for continuous rather than batch processes if equally good results in every respect can be attained.

It is sometimes possible, with great advantage, to convert existing batch processes to operate continuously. For example, large batch evaporators may cause very heavy peaks, particularly if started up on cold liquor. It is often possible to change over to continuous working even with corrosive or crystallising liquors by suitable arrangement of feed and extraction pumps, and good control of steam and temperature, which may be automatic.

If batch working cannot be avoided, the aim should be to take the maximum advantage of diversity by arranging that no two user units go on the line at the same time. This can be more easily achieved if the factory layout is such that all these users, even though their functions be diverse, can be kept under the control or at least the supervision of one man.

So far as is consistent with other economic or process requirements, the size of the units may be arranged to approximate to a continuous process as regards their service demands.

Where steam peaks of big amplitude cannot be avoided, but are of short duration, the steam accumulator may be the correct tool to use. The capital cost of boiler plant installation may be reduced and the practical economy of steam raising improved by smoother working, but the capital cost of the accumulator itself is high, and its operation is based on the unsound practice of degrading energy, since the potential of the steam is lowered irreversibly without the benefit of producing power. The pass-out engine or turbine avoids the latter disadvantage, and may help to level out the load on boilers when steam load fluctuations are of longer duration and moderate amplitude. Their use is particularly appropriate where there is a constant power load.

From the point of view of power and heat balance, process works can generally be divided into three groups :—

(1) Those in which the heat required for process use can just be made to generate the amount of electrical or mechanical power which is required ;

(2) those in which the heat requirements are in excess of the amount needed for power purposes ; and

(3) those in which the power requirements cannot be met by utilising the process heat through the highest practicable temperature range in a heat engine.

The balanced factory is the ideal, but it can only rarely be achieved, and it is generally found that the balance tends to become upset. The reasons for this are that advances in heat economy are usually greater than those of power, and measures taken to economise labour usually involve increased use of power, so that requirements for the latter tend to predominate.

Where the amount of power required is less than could be generated from the heat requirements by means of efficient plant, it is obvious that the first step is to adopt every possible means of heat economy. If, after this has been done, the heat requirements are still in excess, this fact should be no excuse for not generating every available kW of power. The excess energy may be made use of in a variety of ways. It may be possible to instal an ancillary process offering a profitable use, as, for example, an electrolytic process. It may be possible to arrange to supply a neighbouring works, to the mutual advantage of both parties.

The most logical way of disposing of surplus power is to deliver it into the supply authority's mains. This is not usually permitted, or at best, no credit is given. This is a national calamity. Such export of power should be encouraged wherever it is possible, even in the case of small capacities, and full credit should be given for it, either as a money payment, or at least as a valuable offset against the cost of standby capacity provided by the supply authority.

When a factory presents an unbalanced condition of this type, it may be well worth while considering the use of vapour re-compression or other form of heat pump. The suitable case would be one in which a very large quantity of heat is required at a low temperature. In such a case, less than the total heat requirements would be generated in the boiler plant as high-pressure steam. This steam would be used to drive an engine or turbine and exhausted to provide part of the process heat requirement. The power of the engine would be used to drive the compressor of the heat pump taking heat from the warmest available source and raising its temperature sufficiently to provide the remainder of the heat requirement. The amount of heat so pumped depends on the relation of the temperature of use to that of the heat source, but may be several times that of the heat extracted from the original steam by the engine.

Vapour recompression evaporators using rotary or steam-jet compressors are examples of heat pumps which are in fairly common use. Such schemes are likely to be high in capital cost and call for high quality management and maintenance, but they should not be ruled out without adequate investigation. It will certainly be necessary to design the process and the heat transfer arrangements to use the heat at the lowest possible temperature in order to obtain the highest possible coefficient of performance.

The third case is that of the factory which requires more power than can be generated from the heat which is needed. The first problem is to decide how much power can be produced from back-pressure or pass-out machines working between the highest and lowest temperatures and pressures which can be justified. The selection of these figures has already been discussed. The next question is how the balance of the power is to be obtained. It may be done by increasing the condensing capacity of the pass-out sets or by installing additional condensing machines. It must, however, be remembered that while back-pressure operation, with profitable use of the exhaust steam, offers efficiencies with which no condensing station can compete, as soon as condensers are employed the plant is in direct competition with the central station, and, unless it is on a very large scale, it is not likely to show to advantage.

In most normal cases, the best overall fuel economy will be obtained by generating as much power as the process steam will produce in a straight back pressure machine, and by taking the balance of the power requirements from the supply mains. To produce the best results, the generator of the back pressure machine should be paralleled with the incoming supply, and the set should be governed to maintain constant pressure in the back pressure mains. This arrangement will ensure that every pound of process steam will generate its quota of power, except that, with an extremely peaky steam demand, it may be in the interests of capital and running economy to bypass the highest peaks of short duration through a reducing valve.

The usual cause of the frustration of such schemes for national fuel economy is the refusal of the supply authority to permit parallel running, or alternatively, the price demanded for standby capacity is so excessive that the arrangement is put out of court on economic grounds. The obvious alternative is to instal standby capacity in the factory, but in the case of small and moderate size plants, this is not the most reasonable solution, if a broad view is to be taken of the national economy of capital equipment.

In determining the price which should be paid for standby capacity, the chief engineer of a municipal supply department once stated that he must make a charge high enough to pay for installing and maintaining additional cables, switchgear, generators and boilers capable of providing the specified capacity at all times. Such an attitude is disingenuous. Any chief engineer of a supply authority knows the value of diversity, and should give credit for it in this respect as much as in any other.

If a factory requires a really large supply of electrical power together with a moderate quantity of steam, both at a high load factor, there should be a first-class case for building the factory alongside a central station taking the power direct from the station bus-bars with low transmission costs and losses, and the steam by stage bleeding from the turbines. Unfortunately, it is difficult to find an authority which will co-operate in such a scheme.

It is to be hoped that in a few years it will be possible to solve the problem of works which require large power and little heat by the installation of gas turbines, exhausting to waste-heat boilers.

MATERIAL HANDLING

Just as a factory should be so laid out that long ranges of steam mains are avoided, so also the designer should take account of the handling of materials with a view to economy of labour, capital and power.

If the process involves the handling of very large quantities of materials continuously throughout the year, there should be little difficulty in devising a satisfactory arrangement. Incoming wagons of bulk materials may be weighed and emptied on wagon tipplers and the material may be conveyed by belt conveyors and put into stock piles or withdrawn from there by such means as scraper conveyors, or in the extreme case by bulldozers and by scraper excavators. In such cases, the economy of capital, labour and power would be high and the most important points to watch are good management and maintenance.

In works where the quantities are small and diverse, portable conveyors and mobile cranes may be the best tools to use. Labour economy will probably be the most vulnerable factor.

Usually, the most difficult cases are those works of moderate size where fairly large quantities of diverse materials have to be handled. The worst case of all is that in which materials have to be dealt with at high rate, say as ships' cargoes, but only on a few occasions during the year. At these times, heavy equipment is badly needed, but the high capital commitment cannot be justified owing to the low utilisation factor.

The solution which should be aimed at is so to lay out the factory that, if possible, several such handling duties are grouped together in such a way that they can all be dealt with by the same equipment. For example, one railway wagon tippler might be arranged to discharge boiler fuel as well as cargoes of sulphur or other bulk material. Although the capital cost of the tippler might not be justified for either duty separately, it may be economical for the combined quantities. Such a scheme can only be arranged if the works are so laid out that each material can be delivered from the tippler to its proper destination by a practical system of conveyors and elevators.

A valuable tool for some mixed duties is the overhead telpher crane, with or without grab. The crane can be arranged to command a length of siding on which wagons may stand, as well as a number of stock piles or receiving hoppers so that each material concerned may be discharged from wagons to stock, and from stock to the point of usage by the same machine. A grab will not discharge wagons as effectively as a tippler since it is always necessary to clean up the bottom of the wagon by hand. However, there is a considerable economy in labour as against hand discharging, and the capital cost need not be excessive since, as well as discharging, the crane may do its own conveying and elevating.

A valuable application of a telpher crane and grab may be the rough blending of boiler fuels. Alternate grabs-full can be taken from two wagons or stock piles containing different types of coal. They should preferably be dumped into separate hoppers with feeders delivering on to a mixing belt or worm conveyor. If no such plant is available, alternate grabs may be dropped direct into the boot of the elevator or other plant which feeds the stoker. No one would claim that such an arrangement gives real blending, but in the works for which the author is responsible some of the fuels which are received definitely will not burn on the grates to give anything like the output which is required, unless some less bad coal is mixed in this way.

The Scotch derrick and grab is another type of installation of moderate capital cost which might be used to handle a variety of materials from wagons into or out of stock piles disposed radially around it, and such an arrangement could also no doubt be used for mixing fuels.

The Scotch crane calls for a rather higher level of skill to operate it safely than is the case with the telpher, and the area which it commands cannot be so readily extended as can that of the telpher.

ECONOMY OF WATER

The use of water for process purposes often has aspects which are very similar to those of the use of steam. Water is commonly used for two purposes, (*a*) for transferring heat both for heating and cooling operations, and (*b*) for the purposes of process reactions and solution, under which heading may be included many cases of scrubbing effluent gases and the removal of waste products to disposal.

These two aspects can often be considered together with advantage, since, for example, water for reaction may be required at a temperature which can be provided by the carrying out of a cooling operation.

When water is used for removing heat, it is frequently required to do so at the lowest available temperature. In this respect, it is analogous to, but the inverse of, the use of steam for heating, and just as heat should, where possible, be applied at its highest temperature to make the intake temperature T_1 a maximum, so also cooling water should be applied to the same service at its lowest temperature in order to make the exit temperature T_2 a minimum.

Water is in itself a valuable commodity, and in almost all cases its use involves capital cost for installation and power for pumping. After use for low-temperature cooling it should be passed on progressively through duties which may be cooled at successively higher temperatures and finally, having collected all the low-grade heat which may be made available in this way, it should be appropriated to those duties in which this low-grade heat may be valuable, either for space heating, lime-soda water softening or boiler feed.

Once again, these economies will be most easily and effectively achieved if they receive consideration in the early stages of factory design.

THE ECONOMICAL USE OF LABOUR

In considering the economical use of labour, a broad division into categories of skilled and unskilled is convenient, although frequently there is no clear line of demarcation.

A wide use of unskilled labour is often associated with a saving of capital costs and a saving of the use of skilled labour for the maintenance of machines. As an example, a battery of hand-fired Lancashire boilers does not, generally speaking, make heavy demands on the maintenance and instrument departments or on the laboratory for the control of feed water. Even the engineering staff will not often be called out in the middle of the night because the coal is putting the fires out.

On the other hand, highly rated water-tube boilers with mechanical firing reduce the amount of unskilled labour which is required, but make heavier demands on the service branches. While full automatic control will probably not save one man per shift on the firing floor, it will certainly call for a substantial fraction of an instrument man and probably a fitter or electrician to keep it working. Justification for automatic control should be looked for in more efficient boiler operation and greater power production by maintaining a more constant stop-valve pressure on the turbine or engine.

A CO_2 recorder can be a most valuable aid to increasing the day to day combustion efficiency of boiler or other furnaces. It is useless to instal such an instrument unless provision is made to keep it in good working order, and to apply the information which it makes available. In order to get the best results in this direction, it may be that a bonus should be paid on CO_2 but this may be a dangerous cause of discontent, unless the instruments are kept in first-class working order, and for this purpose a man of good intelligence and skill and of high integrity must give an important part of his time to this one job. The savings should very well cover this expenditure, but in planning a factory provision must be made for an adequate instrument department and workshop, and it is advantageous if this shop can be close to the engineer's office so that to the man in charge of instruments can be assigned the duty of bringing to the attention of the chief engineer any notable or unusual irregularities or other information which the instruments provide.

ECONOMY OF CAPITAL AND MANAGEMENT

Reference has been made in preceding sections to the relation between capital expenditure and other aspects of economy. Chemical processes differ in the extent to which capital charges influence total costs. In the case of fine chemicals, they are not usually very important, and there should be very little case for restricting fuel economy measures on this score. On the other hand, the smaller fine chemical companies do not always spend enough money on good engineering management to ensure high energy efficiencies.

It is on the heavy chemical side of the industry that capital charges often assume significant proportions, and once the capital cost of the equipment has been incurred, nothing can be done to reduce these costs, except by writing off against profits, or by increasing the output of the plant.

Since chemical plant is always subject to change and improvement of process its value must usually be written down in a fairly short period, and this fact increases the difficulty in justifying heavy expenditure on items which will increase fuel economy, as, for example, those large heat transfer surfaces which make for small irreversible heat drops.

Fortunately, steam-raising and power-generating plant can generally be written off over longer periods, and it is therefore easier to show cause for installation of the best and most efficient plant which is available.

It appears that in the future much heavier capital costs will have to be carried for firing equipment. In the past there was good justification for providing moderate size boilers with simple grates and induced draught only, to burn good quality washed and sized coals, but now that there seems to be no prospect of obtaining anything but slacks of widely varying volatile, ash, moisture and screen analysis, it is necessary to adopt much more costly plant to ensure maintained efficiency and, what is even more important, maintained ability to carry the factory load.

The capital cost of extensive instrumentation will be high, and if it is not combined with good management to make use of the data thereby obtained this cost will be of no avail, but on the other hand, good quality managers will be used at something less than their maximum efficiency if they are not provided with adequate instrument records.

The main fact which emerges from this discussion is that, as the power to calculate and the power to exercise judgment are both required in high degree if works are to be designed and built for the best economy, then it is only by employing designers and managers of the highest quality and in adequate numbers that this country will be able to offset its shortage of other assets, and so compete successfully in world industry.

Discussion

Mr. Grey said that peak loads were probably the most serious offenders and the importance of load factors on steam consumption could not be overemphasised. It was very difficult to estimate in advance what conditions would be and the amount of standby plant required. The lower quality of coal now being supplied was an additional difficulty as it was also extremely difficult to design a plant to keep running on all the types of coal now being received. Thus, there appeared now to be three main variables on chemical works : (1) steam load, (2) power load and (3) fuel. By-pass connections, condemned by Mr. Vigers, were necessary, even though trouble was often experienced with by-pass valves, especially after the boiler had primed.

Mr. Mason referred to the practice, particularly in many of the older industries in the North, of using live steam in process vessels. It was difficult to control consumption of steam used in this way. He asked that steam jackets or steam coils should be generally adopted in place of live steam.

Mr. Brundit pointed out that films or deposits forming on heating surfaces reduced heat transfer so greatly that sometimes live steam must be used. The use of steam coils led to savings, however, where they were practicable.

Mr. Vigers, replying, agreed with Mr. Grey on the importance of load factor and said that a great deal also depended on whether a plant worked an 8-hour or a 24-hour day. He agreed also on the difficulty of determining the amount of standby plant. It was very important to keep everybody working with the limited amount of coal supplies available. Where power is being generated and steam pressure failed, the position was not eased because steam was available and power was not, since both were required ; the firm would not be appreciably worse off without the possibility of by-passing steam ; however, the by-pass reducing valve was, he agreed, a necessary evil. Replying to Mr. Mason's point he said that the essential was to obtain high rates of heat transmission ; sometimes it paid to use live steam, as, for example, where high-pressure steam was being used by coils which could be replaced by pass-out steam used directly.

Mr. John Phillip wrote referring to certain difficulties connected with the adoption of a combined power and heat plant. The case concerned the reinstatement of a factory damaged by enemy action in which process steam was needed for a colour works. Difficulties occurred because the electricity authorities demanded a heavy charge per kW installed if the works installed its own generating plant ; ultimately this charge was withdrawn on the works agreeing to take half the load from the supply authority and to generate the other half from their own set, this set supplying the steam load for process ; the generator set would reduce the supply taken from the authority during peak loads. In the same region, it was proposed to run a heat pump and it was considered that electricity supplied for the motor driving the heat pump should be charged at heating rates. The supply authority maintained, however, that the efficiency of the heat pump was such that electricity used for this purpose could stand the highest rates of charge.

The layout of chemical works for economy in the use of energy was frequently bound up with the reduction of peak loads. Although the method of dealing with existing works would be different from that of dealing with new works, in both cases it would seem advisable to analyse the energy entering the factory in equivalent tons of coal and set off against the units of output. It was often very difficult to make changes in the face of tradition.

The writer quoted a case of peak load reduction of electricity where the peak load was reduced from 325 kVA to 275 kVA by the installation of a maximum demand alarm. The cost of the installation was saved within three months by the reduction in the electricity account, since not only was the maximum demand charge reduced but also the consumption of current.

In the layout of new factories economy could often be secured by re-arrangement of the process, for example, by replacing a single storey factory by a multi-storey building allowing gravity flow. Too much attention had been paid to capital cost and too little to operating cost. With the present cheap money, the writer hoped that manufacturers would realise the advantage of investing in improvements in the efficiency of their plant. Manufacturers in the past had often not written off their plant over a sufficiently short interval.

3. The Inhibition of Corrosion

By W. F. GERRARD, A.R.I.C., F.C.S., M.INST.F.

FOREWORD

The connection between corrosion of metals and fuel wastage may not be so obvious as that which exists, for example, between heat losses and boiler scale, but it is a very real one nevertheless. In fact, when the enormous quantity of fuel consumed in the manufacture of new equipment needed to replace that rendered prematurely useless by the ravages of corrosion is considered, the more subtle enemy may well prove to be the more formidable.

It is generally appreciated also that plant outage can have a serious effect on fuel consumption and failures due to corrosion are among the most frequent causes of compulsory stoppages.

Evans[1] defines corrosion as "destruction by chemical or electro-chemical agencies" in contrast to erosion, which means "destruction by mechanical agencies". He quotes the rusting of iron as an instance of corrosion and the filing of iron as an example of erosion. Several writers have drawn attention to the identity existing between the products of corrosion and natural ores, and Watts[2] has aptly described corrosion as "a major industry in reverse—all loss and with never a profit". The elemental state is abhorrent to most metals, and iron the most important of them all, will miss no opportunity to revert to the oxide, carbonate or sulphide.

CORROSION MECHANISMS

A clear appreciation of the fundamental corrosion processes is essential to the correct interpretation of a given case and greatly improves the chances of finding a satisfactory answer to the problems at issue. Even in dry air, freshly polished specimens of iron and steel quickly develop a surface film of oxide which slows down or "stifles" the conversion to oxide, though Vernon[3] has demonstrated that specimens continue to gain in weight owing to oxidation after months of exposure. Following a lead given by Vernon,[4] Murray[5] polished a number of specimens cut from the same piece of mild steel. Some of these were exposed directly to the laboratory atmosphere, while others were surrounded by a muslin cage. The method of suspension and all other conditions were the same for the two sets of specimens.

Those in the " direct exposure " group rusted rapidly, but those protected from soot and dust particles remained bright for the duration of the experiment (three months). The muslin cage was then removed, but only slight tarnishing occurred during a further three months' exposure. The superior resistance of the protected specimens was attributed to the formation of a uniform oxide film over the surfaces. Finally, both sets of specimens were immersed in Liverpool town water with deliberate aeration. Rusting continued apace on all specimens of the " direct exposure " group, but those which had been " cured " by protection in muslin were only attacked at the points of support where the oxide film was weak or ruptured.

A second experiment on the same plan employing improved suspension technique is in progress and it is already evident that a uniform film of oxide confers a high degree of protection against rusting, both in air and in water.

Putting this conclusion in a more general way : the rate at which iron is corroded in air and in water is proportional to the rate at which oxygen reaches the surface of the metal.

ACTION OF ACIDS

With this in mind, the action of acids is capable of a simple explanation. Iron oxide reacts with dilute hydrochloric, sulphuric and hydrofluoric acids with production of the chloride, sulphate and fluoride of iron, all of which are soluble in water. Thus a fresh metallic surface is successively exposed, oxidised and dissolved, and so the cycle proceeds until the acid is exhausted or the specimen disappears. Lead resists sulphuric acid, silver resists hydrochloric acid, and magnesium, normally one of the most reactive of metals, withstands the action of hydrofluoric acid, because lead sulphate, silver chloride and magnesium fluoride are insoluble and take the place of oxide as protective films.[6]

Acids such as HCl and H_2SO_4 are present in small amounts in the atmosphere of industrial areas and in water supplies contaminated by waste liquors, but there is another impurity which, though its acid properties are less strongly marked, far outstrips them in importance because of its universal distribution in air and water. Carbon dioxide is produced by the respiration of all animals, by decay of organic matter and by combustion of any substance containing carbon. It is miscible in all proportions with air and so is ubiquitous in the atmosphere. If a sample of air were collected over the North Pole it would still be found to contain an appreciable amount of CO_2.

Pure water has a neutral reaction, but when a trace of CO_2 is dissolved the water takes on a distinctly acid character. CO_2 is often called carbonic acid gas owing to the supposed formation of carbonic acid :

$$H_2O + CO_2 \rightarrow H_2CO_3$$

SURFACE WASTAGE

Whether H_2CO_3 really exists as a true chemical compound or not is of little moment, but the acidic reaction of CO_2 in water is a matter of the utmost significance. By its agency the film of oxide, which we have seen to be the main defence against corrosion of iron and steel, is converted into the relatively soluble carbonate which in turn decomposes into iron hydroxide and CO_2. The joint action of these two gases, oxygen and CO_2, is the commonest cause of general surface wastage, especially on iron and steel in contact with flowing water, which carries away the corrosion product (iron hydroxide) and is coloured red or reddish-brown in consequence. Sometimes the " red water " trouble is a greater nuisance than the corrosion problem itself. When the oxide film is constantly worn away by the scoring action of air, water or mechanical friction, so that the metal surface is continually exposed along a limited track, the result is popularly called " grooving ".

ELECTRO-CHEMICAL ATTACK

Surface wastage, then, is a purely chemical process, but there is another and more dangerous form of attack due to electro-chemical causes and characterised by pitting. Differences in electrical potential on metallic surfaces can arise from a variety of causes, for example, if two dissimilar metals such as iron and copper are in close proximity, the salts dissolved in water may behave as conductors in an electric cell with copper as the cathode and iron as the anode. Reactions at the electrode surfaces will then result in solution of the iron and formation of alkali at the copper with precipitation of iron hydroxide at some intermediate place. Again, many metals, including iron, are anodic towards their own oxides and attack will be possible in localities where the oxide film is weakened or broken.

A third type of electro-chemical corrosion occurs when the distribution of oxygen is unequal over a metal surface, the parts in contact with oxygen behaving as cathodes towards the unaerated parts.

Activity of this kind is said to be due to Differential Aeration and is obviously liable to take place at or near water-line where the supply of oxygen is constantly replenished from the atmosphere, or at points in an installation where bubbles of oxygen can lurk, as at bends in pipe-lines.

The theory of Differential Aeration accounts for the fierce corrosion which often goes on underneath a layer of scale, sludge or paint when the metal nearby is exposed.

Underground installations in particular are subject to yet another type of electro-chemical corrosion by external E.M.F. When stray electric currents escape from tramways, electric railroads and power circuits generally, extensive damage may result because

(1) The rate of attack is independent of the rate of oxygen supply and is determined solely by the strength of the stray current.

(2) The corrosion products deposit at considerable distances from the site of attack and do not stifle the reaction.

(3) If there are breakages in any protective coatings applied the activity may merely be concentrated on a few places and bring about speedy perforation of the pipe or plate.

Hayman[7] mentions a case in which intense corrosion followed the leakage of current from a tramline to a gas main, thence to a water main and finally back to another tramline. The British Post Office has devised special methods for dealing with difficulties brought about by the same kind of mechanism in telephone cable-sheaths.

Electrolysis can cause deterioration of metal-work above ground, notably when stray currents are passing in steel embedded in concrete which has been mixed with water of high salt content ; in electrical equipment where insulation is faulty or the earthing unsatisfactory and on board ship where paint has been removed, e.g. by friction while launching.[8]

It need hardly be said that electro-chemical corrosion of all types is stimulated by contact between metals and sea-water, and it would be instructive to know, if that were possible, exactly how much fuel has been consumed in the construction of new ships and in repairs to hulls and replacements of propellers and condenser tubes necessitated for that one reason only.

GRAPHITIC WASTAGE AND IMPINGEMENT

We have not the space to discuss the many and diverse physical appearances exhibited by metals under the influence of corrosion. Nor is this necessary since they all spring from the same root causes, singly or in combination. A glossary of terms commonly used to describe the effects of corrosion is given in a recent paper by Turner.[9] Reference may usefully be made, however, to the phenomena of graphitic wastage and impingement which may be responsible for failures of economiser tubes and turbine blades respectively. When cast iron undergoes graphitic wastage, the metal becomes anodic and is dissolved out by the water leaving a brittle skeleton of graphite. The dangerous feature is that the corrosion can escape notice if an inspection is perfunctory and sound metal may be thinned down to bursting point before it is detected.

The protective oxide film on turbine blades is impaired by impingement from droplets of water travelling at high velocity and so corrosion is accelerated. Similar conditions can exist in condensers and in high-pressure heating systems.

PREVENTION OF CORROSION

The principal methods for prevention of corrosion all derive naturally from a study of the main corrosion mechanisms. They are designed primarily with one or more of the following objects in view :—

(*a*) To consolidate and repair the protective oxide film.

(*b*) To replace the oxide film by another of greater durability.

(*c*) To eliminate the influences which might cause the breakdown of protective films.

(*d*) To neutralise an electrical condition which might lead to electrolysis.

(*a*) CONSOLIDATION AND REPAIR OF OXIDE FILMS

The work of Vernon and Murray, *inter alia*, proves that the early environment of newly fabricated equipment has a vital bearing on its subsequent resistance to corrosion. It should not be difficult to arrange for the " curing " of plant parts, piping and machinery in a dry dust-free atmosphere until the oxide film is strong enough to stand fairly rough usage. There is scope for considerable research on this subject which should lead to a marked extension in the useful life of manufactured articles.

Small percentages of metals such as chromium and nickel when introduced to iron and steel, or aluminium to brass, promote a surface film of mixed oxides more closely grained in texture and more firmly adherent to the underlying metal, and when this can be done without detriment to the usefulness of the product in other directions an increase in the cost of manufacture may be well worth while. The aluminium brass which was produced by a team working under the direction of the late Guy Bengough must have saved the Admiralty enormous sums of money besides making it possible to keep warships in service for longer periods. While we must take note of Turner's view[10] that there is no likelihood of a " cheap completely corrosion-resisting boiler steel ", there still remains a very large potential field for alloy development in the fabrication of the heavier classes of industrial equipment. The principle of mixed oxide film formation may be applied from the outside so to speak for the protection of metals in contact with water by treating the water with a soluble salt of a suitable metal. Perhaps the best known example is the use of chromate and dichromate for the inhibition of corrosion of steel under water. It is believed that chromic oxide is deposited at anodic points by electro-chemical agency, and this carries out repair work at any weak places in the original iron oxide film.[11] There are widely different opinions as to the concentration of chromate required for this repair work, and Murray has[12] shown that much depends upon the initial cleanliness of the equipment to be protected. He has had satisfactory results at concentrations as low as 10 parts per million under favourable conditions and after effective detergent action, but it seems, for the present at any rate, that the method must be largely confined to systems in which the water is re-circulated and that the chromate concentration must be much higher than 10 p.p.m.

All authorities are agreed that chromate treatment is attended by certain risks and that the rate of corrosion may actually be faster if the salt content of the water is too high. It is a defence weapon to be employed with discretion by a competent practitioner.

(*b*) PROTECTIVE COATINGS

Many kinds of protective coatings are employed for the treatment of steel structures and others are constantly under investigation. Among non-ferrous metallic coatings reference may be made to aluminium, cadmium, chromium, cobalt, copper, lead, nickel, silver, tin and zinc, and the application processes include hot-dipping, cementation, electro-plating, metal spraying and metal cladding. In America, rare-metal plating is on the increase and tantalum especially seems to have a bright future for vessels used in the luxury trades, e.g. perfumery and cosmetics. Glass, rubber, and vulcanite linings also become more popular year by year. None of these artificial films and coverings have been entirely satisfactory for protection of metals throughout steam installations or other plant where water is passing at high temperature and pressure and where thermal stresses may be severe. Graphite paint and cement washes have been applied with a fair measure of success to water distribution pipes, storage tanks, internal surfaces of boiler drums and other accessible parts. It is imperative that *any* protective coating should be uniform otherwise intense local attack is likely, and, as a corollary, the surface to be protected must be reasonably clean and free from corrosion products before the coating is put on.

(*c*) DE-AERATION AND ELIMINATION OF CORROSIVE IMPURITIES

We have seen that the affinity of iron for oxygen is the ultimate cause of corrosion in nearly all cases, and it follows that if oxygen is eliminated from the environment the metal will remain unchanged almost indefinitely. This approach is manifestly impracticable for the protection of structures in air or underground, but the removal of oxygen from water can be accomplished either by mechanical or by chemical processes, and is perhaps the most positive step that could be taken for the inhibition of corrosion in steam plant.

The modern mechanical de-aerator is an extremely efficient piece of apparatus ; it has been described in detail in "The Steam Engineer"[13] by the present author. For large water consumers mechanical de-aeration is the answer *par excellence*, but the smaller plant owner may not be able to afford the capital cost or to justify it in relation to the magnitude of his corrosion problem. Sodium sulphite can be employed as the sole agent for oxygen removal, but has some serious disadvantages :—

(1) Skilled control and frequent testing are essential in order to cater for variation in oxygen content.

(2) The method is expensive when dealing with raw water fully saturated with oxygen.

(3) Dosing arrangements must be effective and reliable and the period of residence after the addition of sulphite must be long enough to allow the reaction to go to completion ; this usually means plant of some kind. Certain metallic salts, e.g. manganese sulphate, when added in very small quantities, accelerate the absorption process, but even with that assistance the author considers that the period of residence should not be less than 30 minutes when O_2 exceeds 1-ml. per litre.

(4) Addition of sulphite increases the total solids of the feed water, which involves a corresponding increase in the percentage blow-down from boilers in order to keep the density within permissible limits. As an example, water saturated with oxygen demands ¾ lb. of sulphite per 1,000 gallons, which would increase the total solids of Glasgow water by more than 100 per cent.

Other oxygen absorbents have been proposed and claims have been put forward by many writers, e.g. by Fager and Reynolds,[14] for the absorption value of alkaline tannates, but sodium sulphite still retains pride of place for this purpose.

The adverse influence of acids in general, and of carbon dioxide in particular, can be offset in water-carrying installations by the maintenance of a slight but definite alkalinity, and by control of *p*H value.

Although CO_2 is the only acidic impurity found in all natural waters, others occur locally. Sulphuric acid is fairly frequent in mine drainage water through contact with pyritic seams, and strong mineral acids are often discharged as waste liquors into rivers and canals. In industrial districts traces of sulphur gases can be picked up from the atmosphere. Moorland supplies contain organic acids and so does the effluent from sewage disposal works. Hence it is no exaggeration to say that the first duty of every water treatment chemist is to make sure that a slight but definite alkalinity of the right kind is maintained at all times. The alkaline reaction must be definite in order to prove that the acids have been destroyed and to allow a reasonable margin for experimental error in making the test and variation in raw water quality before the next test is due. It must be slight because excess alkalinity is undesirable in many industrial processes, and particularly in steam generation. Twenty to fifty parts per million of alkalinity expressed as $CaCO_3$ is widely accepted as a practical working standard. The alkalinity must be of the right kind in order to neutralise acid tendencies arising from the breakdown of bicarbonates when the water is heated. Obviously any alkali which is liable to decompose and produce an acid at high temperature would not be suitable as an anti-corrosion treatment of steam plant. The reasons for preferring one alkali to another for specific purposes are closely connected with questions other than corrosion which are outside the scope of the present paper. The touchstone by which one decides whether alkalinity in boiler feed water is of the right kind or not is the test for *p*H value. If the *p*H is above a certain critical value there are sound reasons for expecting immunity from attack from CO_2. The symbol "*p*H" stands for "the logarithm of the reciprocal of the hydrogen ion concentration." Hydrogen ions are characteristic of acids and low *p*H indicates a strongly acid tendency. In water, the perfect neutral compound, hydrogen ions are exactly balanced by hydroxyl ions and the "strength of alkalinity" could be expressed in terms of the hydroxyl ion concentration. But since the hydroxyl ion concentration must necessarily be inversely proportional to the hydrogen ion concentration, it is more convenient to express both acidity and alkalinity in terms of one kind of ion. It is important to bear in mind that *p*H value does not measure the total acidity or total alkalinity, but merely the number of free H ions in solution. It is an indication of intensity rather than quantity, the relation being much the same as that between temperature and heat, or between voltage and electrical energy.

*p*H control for prevention of corrosion was put on a quantitative scientific basis by Langelier[15] and De Martini.[16] They classified CO_2 in water supplies as being of four kinds :—

(1) CO_2 permanently combined as carbonate.
(2) CO_2 temporarily combined as bicarbonate.
(3) CO_2 required to stabilise bicarbonates in solution.
(4) Excess CO_2 over and above classes (1), (2) and (3).

Only the fourth kind, they said, is active or aggressive CO_2, and Langelier proposed an elementary test to show whether CO_2 of No. 4 kind is present or not. The *p*H value of the water is tested before and after stirring with powdered chalk. If the *p*H of the raw water is increased by the addition of chalk, Langelier's index has a negative value equal to the difference between the two results, and the water is corrosive in corresponding measure.

Conversely, if the *p*H value is reduced by the addition of chalk, the index is positive and the water is assumed to be non-corrosive—examples :—

*p*H *raw water*	*p*H *after stirring with* $CaCO_3$	*Langelier's index*	*Character of water*
6·5	8·0	− 1·5	Corrosive
7·8	7·5	+ 0·3	Non-corrosive

Langelier points out that when his index is positive, any tendency towards galvanic action must result in the deposition of $CaCO_3$ at anodic points ; thus the theory takes into account to some extent the old carbonic acid cycle and the newer theory of D.A. as well as the principles of protective film formation and neutralisation of acids.

In my view the index can be usefully employed in the control of treatment for cold water circuits, but in parts of the plant where *p*H is constantly changing due to loss of CO_2, decomposition of bicarbonates and precipitation of Ca and Mg salts, it is easier and safer to ensure that the *p*H is high enough to satisfy Langelier's hypothesis under the most severe conditions which could possibly arise in the plant, and, that being so, all one needs to do is to arrange that the *p*H never falls below 9·0. The prospect of $CaCO_3$ forming a protective scale seems to disappear when phosphate conditioning is in force, and no form of *p*H control can be relied upon to stop attack by dissolved oxygen.

Other inhibitive measures for treatment of water to prevent corrosion besides those mentioned above include the use of colloidal substances such as starch and silicate of soda.

It is known that colloids have a high adsorption capacity for gases owing to the enormous surface area presented by particles of sub-microscopic size, but the method is somewhat uncertain, and a more direct attack on the problem such as that offered by de-aeration and removal of CO_2 by treatment with lime is preferred when practicable.

(*d*) PREVENTION OF ELECTROLYSIS

Although corrosion of steel by electrolysis is possible on above-ground structures, it is a more serious problem in connection with underground pipelines and cables. Not only is the likelihood of picking up stray currents far greater and opportunity for inspection much more restricted, but the acids present in many types of soil often cause extensive deterioration of insulating material, protective coatings and wrappings. Attack is then intensified at the weak spots. Insulation is usually attempted by dipping the pipe in bitumen, coal tar or cement, by coating with zinc by the dip or spray process and by wrapping with various materials impregnated with tar or asphalt. Insulating joints have been employed with striking success by the General Post Office. The method of jointing for protection of pipes has been described by Steinrath and Klas[17] and for cable sheaths by Radley and Richards.[18] The method is a long way from foolproof, and if the number of joints is inadequate or if they are wrongly situated, defects may be multiplied by the creation of anodes and cathodes on each side of the break (Evans[19]). The use of sacrificial anodes has been described by Jeavons and Pinnock.[20] Numerous iron bars sunk in the ground in moist places (specially prepared if need be) were connected to the pipe-line after taking precautions to ensure good electrical contact between the sections over the entire length of pipe. Particular care was exercised to make the covering as perfect as possible. The iron bars thus became the true anodes of the system and suffered rapid corrosion, but the pipe was preserved in excellent condition. In passing we may note that the idea of sacrificial anodes is a very old one—it is at least as old as the use of zinc plates in boilers ! The most modern method of combating electrolysis in underground pipe-lines and one which appears to present the possibility of wider application than any other so far proposed, is known as cathodic protection. Schneider[21] has given a most instructive and enlightening account of the process from which the following passage is quoted :—

> " Cathodic protection protects a pipe by sending an electric current from an outside source to the pipe through the weak spot in the pipe wrapping or to the surface of the bare pipe, neutralising the electric currents that previously discharged from the surface and caused corrosion.
>
> To protect a pipe or other structure cathodically the compensating current must be caused to enter the pipe through the soil. This is accomplished by connecting a source of direct current, to cause a current to flow from the auxiliary electrode, pilot pipe or anode, to the main being protected. When the adjustments of the protective current are properly made, all corrosion of the pipe-line in the area is completely prevented. The corrosion that previously took place on the main line has been transferred to the ground electrode. Preliminary tests are made to determine the capacity of the direct current supply required to protect a given line. The source of current for this test current is usually a portable storage battery, a portable gasoline-engine-driven direct-current generator or a portable welding generator. If a convenient source of power is available a temporary motor generator set or a rectifier installation can be used.
>
> The positive terminal of the battery or other source of direct current is connected to a temporary low-resistance ground through an ammeter and a rheostat. The negative terminal is connected to the pipe to be protected.
>
> Holding the current at a constant value during the test, soil current readings are taken at several points and at the limits of the positive or corroding portion of the pipe-line. In the positive areas the soil current will be found to be reduced or even reversed if the protective current is

great enough. It is desirable to repeat this test for several values of battery current.

When the earth current readings are plotted at a given location against the battery output a nearly straight line will be obtained. This is used to determine the value of protective current required. The value of protective soil current required, in milliamperes per sq. ft. of pipe surface, as indicated by the McCollum earth-current meter, can be determined approximately from the empirical equation :

$$. \quad 1000$$

in which

i = current in milliamperes picked up by pipe per sq. ft. of surface exposed to soil ;

r = specific resistance of soil in ohms per cubic centimetre, as given by Shepard rod, McCollum meter or laboratory test with A.C. bridge ;

1000 = constant, including a safety factor of three, found in laboratory tests on sheet steel. The safety factor compensates for inequalities in the steel, differential aeration, contact with other elements in the soil, such as coke, metallic areas, etc.

The advantage of this equation is that it requires few or no additional tests to obtain the necessary information on which to determine the minimum current required, and is convenient and sufficiently accurate for practical field use."

Schneider stresses that electrolysis occurs only at points where current can escape from the pipe and that entering currents actually protect a metal at the points of entry. The signal advantage is claimed that by cathodic protection defects in the ordinary coatings and insulators can be overcome without excavation of the line, an expensive and inconvenient operation under concrete pavements in busy city streets.

CONCLUSION

Corrosion and its prevention is a science in itself, and it would be idle to pretend that we have done more than to survey the subject very briefly in this paper.

The object has been not so much to study any single aspect in detail as to show that methods are in existence to deal effectively with almost every corrosion problem. It is hoped that the industrial public, perceiving the broad outline of prevention technique and appreciating the intimate relation between corrosion mechanisms and protective measures, will gain confidence in the ability of the experts to solve its problems and will recognise that money spent in carrying expert advice into practice will, in most instances, be regained many times over.

As it becomes more widely realised that protection is cheaper than replacement, the amount of fuel consumed in new manufactures, repairs and maintenance or wasted by avoidable stoppages will be reduced and so the nation will gain while the individual helps himself. If it is true, as Watts states, that corrosion results only in loss and never in profit, then surely the converse likewise holds good with reference to corrosion prevention.

The author wishes to record his indebtedness to :—

His colleague, Wilfred Murray, for valuable advice and for information concerning his experiments in the use of chromates and dichromates.

Dr. Ulick R. Evans, Reader in the science of Metallic Corrosion at Cambridge University, whose book *Metallic Corrosion, Passivity and Protection* he has freely consulted.

Mr. T. Henry Turner, Chief Chemist and Metallurgist, London and North-Eastern Railway Co., for the list of protective coatings.

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Discussion

Mr. C. W. Drane, having regard to the large number of factors influencing corrosion said that he proposed to discuss only two aspects of corrosion inhibition, namely (1) corrosion and fuel losses and (2) the use of protective coatings. In addition to the two points raised by Mr. Gerrard on the first issue there were also fuel losses due to leakages in pipe-lines and elsewhere which often occurred at inaccessible or hidden places, loss of efficiency due to accumulation of the products of corrosion, e.g. in causing obstruction in pipe-lines, and damage to products caused by the products of corrosion. On the use of protective coatings, principally for water, and consisting of films applied prior to use, the speaker while agreeing with the advantages of curing as described by Mr. Gerrard pointed out that damage to the film would lead to corrosion at the gap so formed ; in nearly all cases where a metal appeared to be naturally immune from corrosion, its immunity was due to the formation of an oxide film which was self-healing. The need for protective coatings being complete and free from " holidays " had been emphasised by Mr. Gerrard. If the coating were electrically neutral, all the corrosive materials present would be free to attack at the small exposed surfaces ; if the coating were more noble than the base metal, the base metal would be attacked at an increased rate ; and if the coating were less noble, it would be worn away in patches. With many coatings, however, notably tin and zinc, there was a tendency for reversal of polarity under conditions of attack. The speaker drew attention to recent work on metal-pigmented paints containing up to about 95 per cent. of metals such as zinc with a plastic base. These paints appeared to have the advantage that rust or mill-scale under the coat were reduced to metallic iron and did not cause deterioration to the same extent as with ordinary paints. In distinction to coatings applied prior to use, protective films might be formed by modification of the environment. He said that these films were formed in several ways :—

(*a*) By formation of an oxide film which under the conditions of exposure was self-healing. Chromate treatment was the most familiar example and sodium nitrite was believed to act in the same way. Corrosion in low concentrations was due to the film no longer being self-healing.

(*b*) Use of organic colloidal compounds and silicates. Organic compounds were used as inhibitors in the pickling of steel and the presence of small quantities of organic matter and/or silicate in some natural waters was believed to be the reason for absence of corrosion by waters with apparently corrosive properties.

The behaviour of silicate was not thoroughly understood. Use of silicate in suitable cases had, however, given excellent results at reasonable costs. As with other treatments which were incompletely understood, it was not possible to get consistent results, and when a failure occurred it was not always possible to give an explanation. Success had been obtained using both liquid and rock silicate in the treatment of black-iron hot water systems installed in soft water districts during the war when other material was not available. In one successful case the red-water trouble was remedied and the number of pipework replacements was reduced from one per week to one in six months. In other cases red-water troubles stopped but corrosion remained active. An advantage of silicate was that dosing need not be accurately proportional to the rate of flow and might even be intermittent provided that sufficient was added to maintain the silicate film in a good state of repair.

The usefulness of a film added via the water was dependent on whether it was formed *in situ* or precipitated in the water away from the metal surface. The relative ineffectiveness of silicate in hard water was probably due to the precipitation of calcium silicate in the body of the water.

(*c*) The usefulness of phosphates in threshold concentrations for scale prevention was well established but experience with its use for prevention of corrosion was limited. The American Army reported most satisfactory results in corrosion prevention with mixtures of silicates and phosphates. In this country mixtures of tannins and phosphates had been successfully used for cooling systems.

(*d*) Controlled calcium carbonate deposition based on the work of Langelier was very promising. Apart from some work on cooling circuits most of the experiments in this field had been done in America. There were quite a number of factors to take into consideration and each case required very careful examination.

In concluding he agreed that removal of oxygen and maintenance of suitable alkalinity were the most certain methods of corrosion prevention. There were, however, numerous cases, especially if the anti-corrosion treatment were initiated when the plant was new, where the cheaper methods discussed could be satisfactorily employed. In some cases, such as open cooling circuits, removal of oxygen was impracticable and alternative methods had to be applied.

Mr. Mellanby drew attention to the bad system of fitting reducing sockets of iron between copper pipes and copper unit heaters. This system led to excessive corrosion.

He also gave an account of his experiences with a hypochlorite plant. He had tried rubber and stainless steel, both unsuccessfully and finally obtained relief by using ordinary black iron entirely covered with pitch.

Mr. Grey noted that Mr. Gerrard had not mentioned the effects of stress and strain on corrosion, particularly on tube-plates in condensers. Was it true that if the metal were under stress corrosion was increased ?

Mr. Gerrard, replying to the discussion, agreed with what Mr. Drane had said. Referring to Mr. Mellanby's point on the use of dissimilar metals in contact, he noted that many well-known unit heaters were still being made from copper alloy tubes with mild steel heaters, a combination extremely bad from the corrosion point of view. Care should be taken to use homogeneous metals wherever possible. The use of pitch for protecting underground mains was well known, but like all other covering systems must be entirely homogeneous or corrosion was accelerated. Stress was certainly very important, but little could be done about it except by the designer.

Mr. G. H. Challis wrote : Mr. Gerrard has made the point that many metals, including iron, are anodic towards their oxides and electro-chemical attack will be possible in localities where the oxide film is weakened or broken. This point deserves emphasis and should be carefully noted by purchasers of new plant comprising units fabricated in mild steel.

There is still in some quarters some loose thinking regarding the oxidation of mild steel surfaces, as it is not always appreciated that the mill-scale coating with which steel leaves the mills consists of oxides of iron. This scale gets broken during the handling and weathering the material receives during fabrication, leaving exposed steel surfaces which are anodic to the remaining scale and the condition Mr. Gerrard describes is then present. Painting over the surfaces will not prevent electro-chemical attack, as it can continue underneath coats of paint with the consequence that eventually the remaining scale becomes detached, bringing the paint coats with it. The remedy is to remove all mill-scale before painting. This can be done in various ways, the more usual being pickling, sand or shot blasting, flame de-scaling or weathering.

For information upon the subject of the preparation of steelwork for painting, reference may be made to the brochure entitled " Protective Painting of Structural Steel " published by the Iron and Steel Institute, which has much practical value.

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4. Fuel Efficiency in the Plastics Industry

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Many of the problems of the efficient utilisation of fuel are common to all branches of industry and need not be considered in detail in this paper, except as regards special points peculiar to the plastics industry. The Fuel Efficiency Committee of the British Plastics Federation naturally started by investigating the extent to which the common principles of fuel efficiency were applied in the industry, and after a preliminary questionnaire a panel of inspecting engineers was formed. The works of most of the members of the Federation were then visited and on the basis of reports received, recommendations were made as to the measures required to improve the efficiency. These mainly consisted in improvements to insulation, especially of small steam connections down to ½-in. i.d., the recovery and utilisation of condensate and flash steam, the efficient insulation of platens from press bodies and the painting of exposed surfaces, especially platen edges, with aluminium paint to reduce radiation losses. It was estimated that this last step would reduce radiation losses from the surfaces so treated by approximately 25 per cent. In addition recommendations were made for improving the efficiency of the generation of steam.

Hydraulic systems are in use in all plastic moulding plants and are a potential source of power wastage if the maintenance of the system is not good. This matter has received the attention of the Fuel Efficiency Committee.

As certain sections of the industry used many small steam-heated presses and other plant units, the efficiency and maintenance of steam traps was also an important feature. Apart from these obvious means for improving efficiency the attention of the committee was forcibly drawn to considerable losses by radiation from incompletely utilised platen surfaces, as a result of which they undertook investigations into the efficiency of such presses and the relative merits of the methods adopted for heating. In this connection the use of back-pressure turbines, or reciprocating engines, should receive careful consideration in the larger works where there is a considerable demand for process steam.

The moulding of the plastic materials is to a large extent carried out in moulds which are heated by contact with the press platens which have to be maintained at a definite temperature, usually of the order of 300° F., and these platens not only lose heat by conduction to the press body, from which they should be insulated as efficiently as possible, but also by radiation to the atmosphere from the platen edges and the unutilised portion of the working surfaces. In addition heat is radiated from the mould itself.

A further fruitful source of heat loss occurs in apparatus for the preheating of the moulding materials before the actual moulding operation. The increasing use of radio frequency preheating for this purpose will help towards reducing the loss.

As regards the intrinsic thermal efficiency of a press, it was shown by experiment that considerably less than 5 per cent. of the heat necessary to maintain the platens at the required temperature was actually used in heating the moulding material itself, the remainder of the heat being dissipated by radiation, conduction and convection. In addition the use of steam-heated presses involved transmission losses by radiation and convection and in condensate and flash steam. These losses are increased by numerous small pipe connections to individual platens. Similar losses occur with pressure hot water but losses in condensate and flash steam are avoided. With gas and electrically heated presses on the other hand, there are no transmission losses and the efficiency of utilisation is higher. As a result of careful tests carried out by members of the committee and of an analysis of operating data received from various member firms it was concluded that the normal thermal efficiency of the steam-heated press is of the order of 28 per cent. on the latent or 20 per cent. on the total heat content, whilst for gas and electricity corresponding figures are 50 per cent. and 90 per cent. These efficiencies do not refer to the heat actually utilised in raising the temperature of the moulding material, but to the heat required to maintain the platens at the necessary temperature when efficiently insulated from the press body.

Various methods may be adopted for increasing this efficiency. In the case of steam-heated presses transmission losses should be reduced to a minimum by effective insulation of all steam mains and pipe connections down to ½-in. i.d., and by the efficient installation and maintenance of all steam traps together with the recovery and utilisation wherever possible of condensate and flash. As regards insulation from the press body an asbestos-cement composition 1-in. thick is generally used, but experiments made by a member of the committee resulted in the development of a bakelite insulation consisting of several superimposed perforated ¼-in. sheets. Tests made by the National Physical Laboratory showed that the thermal conductivity of this special laminated sheet was only 1·6 B.Th.U./sq. ft./hr./in./° F. as against 3·0 for the asbestos-cement material generally used. Radiation losses from platen edges and other unused surfaces can be reduced by the use of aluminium paint, and every precaution should be taken to utilise the working platen surface as completely as possible and to avoid long standby periods when changing moulds. Larger moulds may be heated separately and insulated from the press, by which means losses are reduced to a minimum.

It is obvious that these low thermal efficiencies must result in raising the temperature of the air surrounding the plant, particularly in the case of steam where a high proportion of the loss can occur by radiation from uninsulated piping connections in addition to exposed platen and mould surfaces.

The thermostatic control of platen temperatures has also received considerable attention. This is of considerable importance where electricity or gas is the heating medium. This not only secures greater uniformity in the product, but it increases output and largely avoids rejects. It also results in a reduction in fuel usage which in one plant was quantitatively measured at 20 per cent. Steam heating has several advantages from the point of view of the moulding operator. Temperature can be controlled quite uniformly by controlling the steam pressure, and a wide range of working temperatures can then be obtained by means of reducing valves. The rate of heating is also rapid and is only limited by the rate at which condensate can be removed. This raises the very important question of platen design so as to allow easy and free drainage of condensate. The use of pressure hot water as a substitute for steam has been the subject of a special investigation by the committee. It has a very obvious advantage that, if the system is properly maintained, condensate and flash, together with their accompanying losses, are avoided. On the other hand, various devices have to be adopted when several working temperatures are required, and these somewhat complicate the plant from the engineering point of view. The increased thermal efficiency resulting from the avoidance of condensate and flash varies from 16 per cent. at atmospheric pressure to 30 per cent. at 200 lb./sq. in., but it must be remembered that it is possible to recover a large part of this heat by the installation of an efficient condensate recovery system. The question of efficient steam traps is extremely important in this connection, because the advantage possessed by pressure hot water over steam only exists because in practice the losses from the latter system often exceed very considerably those named above, and the subsequent recovery is often very inefficient. This is illustrated by the fact that the Committee obtained reliable information from several sources that the substitution of pressure hot water for steam heating had resulted in savings as high as 40 or 50 per cent.

The use of gas or electricity obviously has considerable advantages in small works where steam generation on a small scale is often very inefficient, and involves standby losses which are avoided when the heating medium can be switched on or off at will. These methods of heating also avoid transmission losses which often bulk so largely in steam and even hot-water heated plants. They possess certain disadvantages, however, from the operating point of view, which are by no means insuperable, such as lack of uniformity of platen temperature and in the case of electricity a slow rate of heating. The committee considers that thermostatic control is essential for efficient operation with gas and electricity.

As regards costs, these naturally vary with local conditions and under some circumstances, as shown in one of the papers published by the Federation, there may be little to choose between them. Normally, however, a well run and efficient steam or hot water plant is likely to be the cheapest, but as indicated above many other factors come into the picture and a final decision can only be made after a review of all local conditions.

The British Plastics Federation has recently published the reports of the fuel efficiency committee which deal with all these questions in considerable detail, and it may be claimed that a solid foundation has now been laid on which the industry may base calculations for the design of future plant.

Discussion

Mr. James A. Terrett said the heat consumption per lb. of material in his factory was higher than that of a moulding plant because his material was a thermo-plastic. The material was heated in the press by hot water at 185° F. and immediately cured by rapid cooling with water to 40–50° F. ; the heat stored in the platens was thereby lost. Some of these materials required heating at 360° F. with subsequent cooling. Thus a thermo-plastic plant in continuous operation, with six charges an hour, involved a large consumption of heat. Insulation of radiating surfaces had proved effective. It was hoped by the F.E.C. of the plastics industry to issue recommendations for standard practice. Electrical or gas heating had often been shown to be more efficient than steam heating, but when heating was followed by immediate cooling only steam or hot water could be used. Steam pressure on the speaker's plant was solely a means of obtaining the requisite temperatures and it was very necessary that pressures should be steady. Peak loads were prevalent and persistent and could not be levelled by co-operation between plant and boilerhouse ; this type of plant with demands ranging from 6,000 lb. to 12,000 lb. in a few minutes was ideal for a steam accumulator, or, since the electrical load was usually much in excess of the steam demand, for back-pressure generation. Considerable differences were observed between the results secured on the boilers by different men, amounting to 7–10 per cent. variation in steam production ; if possible, the best men should fire during the heaviest load.

Mr. J. Butler spoke of the difficulties, in a works using 70 tons of boiler coal a week, of training works personnel in the normal everyday practice of plant maintenance and boiler firing, steam trapping, etc. When making an attempt to eliminate flash steam at the boiler feed tanks, the operators persisted in the view that the elimination of an eye-sore was the most important thing, conservation of heat being very secondary. The pressure in the condensate mains was found to be between 40 and 60 lb./sq. in. Having ascertained that the boiler feed pumps would work well against a 20 lb./sq. in. back pressure, it was arranged to feed all condensate into a tank suitably trapped, expand to 10–20 lb./sq. in. and use it for panel heating in place of live steam. A feed was installed from the live-steam mains through a control and reducing valve to supply make-up if and when the low-pressure system demanded it. This arrangement worked well and lightened the task of the boiler men. They believed the good results to be due to their own improved stoking while the maintenance men claimed it as the result of their good work. In due course the works personnel learned by example and precept to watch matters of fuel and steam wastage as carefully as they watched other works practice. The result was that the factory was heated better and less coal was used than was at one time needed to heat the press platens alone. The following winter, however, the factory could no longer be heated by exhaust steam alone. This was due to still greater overall steam saving whereby less condensate was produced—and the coal consumption was down to 35–37 tons a week. Mr. Butler also referred to the possibility of using the heat pump system on the hot water obtained by cooling the presses.

Mr. Brundit declared that the 40 per cent. increase in efficiency obtained by changing from a steam to a high-pressure hot water system was realised only because the steam had been used inefficiently in the first place. It was probably fair to state that steam was at least as efficient as hot water and could be even more efficient with good trapping under some conditions.

Mr. R. F. Hayman said that certain operating difficulties of gas-heated platens mentioned by the authors were due to the difficulty of providing sufficient air for the combustion of a relatively large quantity of gas in a confined space. This difficulty was overcome by the use of high-pressure gas combined with a flame-proof saw-cut burner to give a stable flame. The need for installing a gas compressor was against this solution for smaller works but a recent development had been a more efficient injector capable of providing the necessary degree of aeration using low-pressure gas ; the air/gas ratio of these injectors was 3 : 1 as compared with the normal ratio of 2·2 — 2·5 : 1. Thermostatic control of platen temperatures was important and the speaker had found a satisfactory device to be remote control capillary thermostats, liquid or gas filled. Work, which should shortly bear fruit, was in hand on improved methods of heat transfer to platens. The low utilisation efficiency, i.e. based on heat actually going into the moulding powder, of 2–5 per cent. was not a problem peculiar to the plastics industry. The efficiency of cooking food in a domestic oven, for example, was only 3 per cent. for single loads, though up to 25 per cent. for full loads.

Mr. Hilton asked whether it was desirable in the interest of fuel economy to change from steam heating to hot water or electricity, whether oil should be used as a boiler fuel and whether in the event of serious shortage of coal supplies, priority would be given to those firms who had made their plant more efficient.

Mr. Chalk, replying to the discussion, agreed with Mr. Brundit's statement. Thermostatic control was essential to obtain good moulding and high thermal efficiency. There was a wide difference in temperature from one form of platen to another, and it was not always safe to use the steam temperature as a criterion of the face temperature. The Minister had declared that the conversion of solid-fuel fired appliances to oil was now finished and said that he did not wish to discourage the installation of appliances for burning low-grade fuel.

The Chairman of the Session, **Dr. E. V. Evans,** summarised the principal conclusions as follows :

The industries for which I speak deal with some 50 million tons of coal a year. In each of these industries voluntary organisations for conserving fuel have been established during the war years. There is a friendly and stimulating rivalry in fuel efficiency between the separate units of the industries.

In the carbonising industries, the problem has been to make the best use of existing plant and it may be said that, despite the difficulties of the war period—and these industries have had a great many difficulties including shortage of labour, the deterioration in the quality of the coal, and the difficulties associated with the ageing of plant—it has been possible to maintain a high thermal efficiency. A fine piece of team work has been effected and this team work will continue to operate. A fair proportion of the plant in existence was designed at a time when fuel economy was less important as an issue than it is today. Coal was cheaper and considerations of capital cost limited the full employment of fuel-saving devices. It is obvious from the papers that have been presented that new plant will take much greater account of those principles of design which lead to the utmost thermal economy. Each plant and each process presents a different problem in the balancing of heat and power requirements and the solution of these problems of applied thermo-dynamics will be a primary feature of any future plant design.

Many interesting references were made by authors to indirect fuel savings. It was pointed out, for example, that a high degree of efficiency is possible with gaseous firing because that fuel is capable of active control and the furnace can be designed to fit the work schedule. Moreover, the production of goods with a small proportion of rejects itself represents a real and substantial saving.

All three industries represented in this section are facing a large programme of work in maintaining the efficiency of existing plant and then, as opportunity offers, designing, erecting and operating new plant.

Attention has frequently been drawn to the primary importance of an adequate supply of technical personnel, both for the design and for the operation of the plant, technicians who can establish a chain of intelligent co-operation from the inception of the process to the last detail of its working.

The carbonising industries have made a very special point of the fact that their plant is designed to deal with coal of specific characteristics. If those characteristics vary outside a certain range, the performance of the plant is inevitably less efficient and indeed can be most wasteful.

SECTION F

SPECIAL INDUSTRIAL SESSIONS

Chairman: PROF. D. T. A. TOWNEND, D.SC., PH.D., F.INST.F.
MEMBER OF THE FUEL EFFICIENCY COMMITTEE, DIRECTOR OF B.C.U.R.A.

SESSION I. The Light and Heavy Clay Industries

Chairman of Session:
MR. A. T. GREEN, O.B.E., F.R.I.C., F.INST.F., HON.M.INST.GAS E.
DIRECTOR OF RESEARCH, BRITISH REFRACTORIES RESEARCH ASSOCIATION

THE CHAIRMAN pointed out that while the chemistry and physics of clay were not under discussion at that session, if true economy was to be realised full knowledge must be available of the physical and chemical changes and the associated thermal reactions taking place up to the stage when the properties desired in the different products were developed. Whilst requirements for different classes of goods were very different, there existed many common factors which allowed fundamental knowledge to be utilised throughout the industry. There was need for discussions on fuel efficiency between fuel technologists, kiln builders and the technologists of clay industries and he recommended that local fuel societies should be formed for this purpose, as had already been done in North Staffordshire.

1. The Utilisation of Town Gas in the Ceramic Industry

By J. E. STANIER, G.M., M.I.CHEM.E., M.INST.GAS E.

Considerable advances have been made in the application of town gas to the various heating processes of the ceramic industry during the last thirteen years, and this is well exemplified by reference to the following graph (Fig. 29). This shows the rapid and spectacular growth in the consumption of town gas for these purposes, and also the increase in the number of town-gas fired kilns since the first one was installed in 1932.

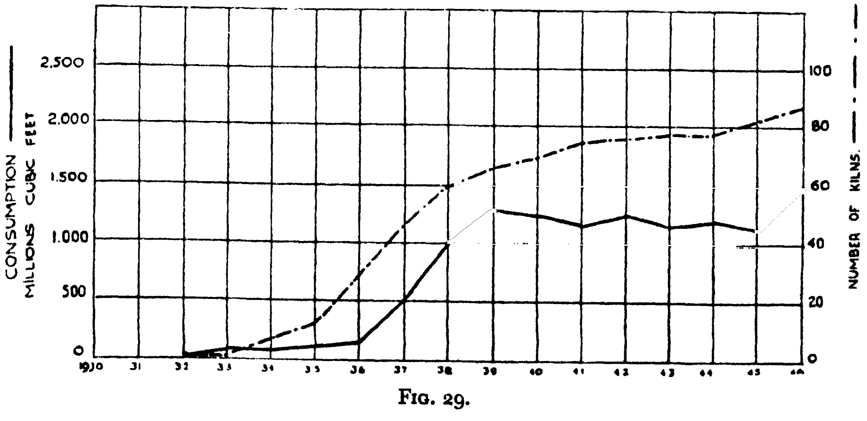


FIG. 29.

During the war years, following the restrictions in production from this industry, the rate of progress was interrupted, but a rapid return to normal conditions was noticeable during the latter part of 1945 and early in 1946 when the total requirements of the ceramic industry exceeded the pre-war figure.

The rate at which new gas-fired kilns are coming into operation, together with a small number of tunnel ovens previously closed down during 1939, can be judged from the returns of the Gas Department which indicate that for the various heat requirements of the pottery and allied industries, the consumption of gas for the June quarter of 1946 was 50 per cent. greater than the pre-war demand.

The results are sufficient indication of the progress being made in the change-over from solid fuel to gaseous firing in the ceramic industry.

The ceramic engineer, when contemplating the introduction of a tunnel kiln, considers the following aspects :—

(1) Economies in fuel ;
(2) Production of better ware ;
(3) Better control of the firing process ;
(4) Reduced labour costs ;
(5) Better working conditions for the attendants ;
(6) Reduced expenditure on saggars ;
(7) Smoke abatement.

Dealing in sequence with the above points of consideration.

ECONOMIES IN FUEL

The following tabulation gives the heat requirements per ton of ware for the periodic kiln using solid fuel, and the comparative figures for town gas in a continuous tunnel kiln, together with the actual weight of fuel necessary if consumed direct at the factory or carbonised at the gasworks for the production of an equivalent amount of gas to fire the same weight of ware.

Class of ware	Therms per ton of ware		Tons of coal required	
	Using solid fuel in periodic kiln	Using town gas in continuous tunnel kiln	Per ton of ware in the periodic kiln	For production of gas per ton of ware in a continuous tunnel kiln
Biscuit tiles	215	83	0·74	1·00
Glost tiles	436	50	1·50	0·60
Sanitary biscuit	519	163	1·76	1·95
General earthenware, biscuit, saggared.	262	120	0·90	1·44
Ditto open placed . . .	—	94	—	1·14
General earthenware, glost . .	355	78	1·22	0·94
Sanitary fireclay . . .	847	120	2·91	1·44
Electric porcelain . . .	372	115	1·27	1·39

A study of these results shows that the thermal requirements for firing the above different classes of ware are on an average in the ratio of one therm of gas being the equivalent of four therms of coal. In the case of glost tile firing, this ratio is increased to 1 : 8½, whilst the firing of general earthenware (biscuit) in saggars only gives a proportion of 1 : 2.

In comparing the tonnage of coal required at the factory for periodic kilns as against the fuel necessary at the gasworks for the production of gas to equal the same tonnage of ware fired by gas tunnel kilns, the following residuals have to be taken into account for each ton of coal carbonised, which would be lost if solid fuel had been used in a periodic kiln :—

8·5 cwt. of saleable coke . . . . = 119 therms
1·0 cwt. of saleable breeze . . . = 11 ,,
15 gallons of tar . . . . . = 26·5 ,,
3 gallons of benzole . . . . = 4·4 ,,

160·9

Assuming that 83 therms of gas are yielded per ton of coal carbonised, nearly double this amount of heat energy is contained in the residuals, either in the form of coke or liquid hydrocarbons.

Taken as an average, a ton of coal utilised at the gasworks is equivalent to supplying the necessary amount of town gas for firing the same quantity of ware as nearly 1·2 tons of coal if used in the raw state in the periodic kiln.

From a coal conservation aspect, town-gas firing of continuous tunnel kilns (if consideration is given to the balance of thermal value of the residual products of carbonisation) is equivalent to a saving for the nation of more than two-thirds of the heat energy of every ton of coal now used in periodic kilns.

Although these comparisons show a vast improvement in fuel saving, there are still considerable reasons for further investigation and improvement. For example, the modern muffle oven operated on general glost earthenware will have a gross efficiency of about 60 per cent., which is of a high order. On the other hand, the weight of ware fired compared to truck furniture will only be in the proportion of three parts of ware by weight to ten parts of furniture, bringing the net efficiency down to a figure nearer 15 per cent.

Whilst some improvement has been made recently in this respect from the figures already quoted, it is quite apparent that further investigations should be undertaken to effect improvements in the kiln furniture with a view to reducing the proportion mentioned above, thereby increasing the efficiency figures, although it will be appreciated that the kiln superstructure must be sound and at the same time have a very low maintenance.

Another factor of importance is that the length and cross section of the kiln should be so arranged that the ware can be fired on the minimum cycle commensurate with getting first class ware, the maximum output obtainable and a low maintenance on trucks and truck furniture. Or, expressed in other terms, it will be found that a kiln with a relatively small, well-loaded truck, firing on the optimum cycle, will be more efficient than a kiln of the same length firing the same output but built with a larger truck and firing on a slower cycle.

This can be well explained when one considers the principle on which a tunnel kiln operates. The goods are fired in counter-current to the combustion air or gases, so that the speedier service and smaller section allow the cooling goods to give up their heat more readily to the incoming combustion air, and for the outgoing waste gases to transfer their heat for preheating the incoming goods.

Experimental work in connection with direct firing, without either muffles or saggars, is being pursued with vigour by the ceramic research engineer, with the object of still further uplifting the thermal efficiency, and in some cases it has proved successful, but whether or not its application universally throughout the many grades of pottery and tiles is imminent is difficult to say.

New types of burners such as radiant cups and radiant blocks seem to offer some possibilities in this direction, particularly so from the fact that combustion is completed within the burner head, totally eliminating any flames from the interior of the tunnel, and it is claimed that it is possible to fire all classes of ware without protective saggars, thus greatly reducing the ratio of weight of gross load to weight of pay load. An additional claim with this type of burner is that they can be raised to maximum temperature in a short time, enabling the tunnel to be brought into production after shut-downs much quicker than when using the conventional type of burner. However, as pottery users normally only close down their oven once a year at most at Wakes Week, this is not very important, and it must be mentioned that this type has a disadvantage in so much as it uses all cold air, thereby losing some efficiency. In addition, the burner equipment is very expensive in first costs.

Another factor in connection with gas-fired continuous tunnel ovens which is of great importance, and which will still further increase the relative efficiency compared with the periodic kiln, is the fuller utilisation of waste heat. This should bring many operating advantages throughout the factory, e.g. heat for space warming in addition to the normal drying operations can be secured from the tunnel kiln products of combustion, the cooling zones and radiation from the kiln structure.

In some cases waste-heat recovery from a tunnel oven might partially eliminate the need for a steam-raising plant, thus saving huge quantities of fuel. It will be realised, therefore, that scope still exists for further fuel economies with gas-fired tunnel ovens in the future.

PRODUCTION OF BETTER WARE, AND BETTER CONTROL OF THE FIRING PROCESS

One important contribution which gas-fired tunnels make towards better ware is that the success of firing is no longer dependent upon the human element. Not only is control greatly simplified, and made entirely automatic if required, but the kiln may be set to any desired firing curve with the assurance that the curve will be constantly adhered to and remain constantly uniform. Temperature variations through the height or width of a setting do not fluctuate as in periodic kilns. Ware is subjected to steady increases and decreases in temperature, as against the rapid changes which may occur even in the most carefully fired periodic kiln. As a result the loss through spoilage in firing becomes negligible.

The absence of solid fuel and the concomitant smoke, dust, ashes and dirt, removes the dangers of dirty and spotted ware which has always proved a serious problem to the ceramic industry and has contributed towards a large proportion of spoiled ware.

REDUCED LABOUR COSTS

Town gas requires no storage space on the works, and leads to a considerable saving in labour charges and other expenses incidental to solid fuel, such as cartage of fuel and removal of ashes. The heavy manual labour attached to firing periodic solid-fuel kilns and the constant attention to fires and dampers are removed entirely. Control of gas-fired ovens can be carried out automatically by reliable instruments, and supervision is reduced to a minimum. Alterations to temperatures or firing schedules are reduced to the regulation of a few valves, and the operator is in the position of knowing that uniform results may be reproduced at any time.

Economies in labour are most marked as regards placing, since the regular output of a tunnel kiln can be dealt with by between one-third and one-half the number of men required to place and draw the saggars in a periodic kiln, whilst the conditions for the workers are infinitely better in every respect. Taking into consideration the fact that the placers with tunnel kilns are in regular employ, as compared with the need for placing teams only when placing and drawing the periodic kilns, the tunnel kiln represents a direct saving of labour of from 25 to 35 per cent.

BETTER WORKING CONDITIONS FOR THE ATTENDANTS

Working conditions in the ceramic industry have improved tremendously following the adoption of town gas for firing and process work. Mention has already been made of the reduction in carrying and lifting ware when placing for firing and the absence of dust, dirt and ashes.

The factory is no longer blanketed in smoke following each " baiting " of the periodic kilns, nor are employees required to enter kilns which are at uncomfortably high temperatures to draw the ware. Temperature conditions throughout the factory are improved and equalised. Heating of shops, drying plant, etc., can be effected without discomfort to the employees.

Yards and approaches can be kept clear of accumulations of ashes or dumps of solid fuel, and give the management an opportunity to set an example in cleanliness and more hygienic conditions which are quickly appreciated by the workers.

REDUCED EXPENDITURE ON SAGGARS

Opinion seems to be divided on the merits and efficiencies of open-fired and muffle-type tunnels, although of late most of the larger firms are building their biscuit kilns open fired and their glost kilns muffled. There is no doubt that the open-fired type would be more efficient for glost firing were it generally practicable to eliminate saggars and place the ware open on the trucks. Town gas as at present distributed is sufficiently low in organic sulphur to have no detrimental effect on many classes of ware, and therefore saggars are not always essential with this type of firing.

Whereas in periodic solid-fuel kilns the saggar has to act as protector of the ware, as well as support to the other saggars in the bung in tunnel kilns, the weight of bungs is greatly reduced, with the result that much lighter saggars can be used. By this means it has been possible to reduce the ratio of saggars to ware from 10 : 1 to 3 : 1 with corresponding savings in fuel consumption. Breakages of saggars for the same reason are much lower, and consequently expenditure is correspondingly reduced.

Whilst saggars do afford some definite advantages as regards placing, there is no doubt that equal advantages could be derived from correctly designed kiln furniture, provided suitable refractories were available. This is a matter which is having close attention at the moment, and the problem, when solved, will have a material effect in reducing fuel consumption and increasing efficiency in firing.

SMOKE ABATEMENT

Out of the approximate tonnage of 1,175,000 tons of coal used for industrial purposes in the North Staffordshire district, it is estimated that some 750,000 tons are used by the ceramic industry and by the brick and roofing tile trades. The majority of this tonnage will be used for firing processes, with smaller quantities being consumed for ancillary purposes such as steam raising, clay drying, etc.

Based on the Gas Department's thermal yields, to produce town gas used for ceramic firing (excluding the brick and roofing tile trades) on the present demands of the industry, some 125,000 tons of coal is required, from which,in addition to the gas, some 375,000 gallons of crude benzole, 1,875,000 gallons of tar and 60,000 tons of coke and breeze were produced. Using the figures quoted above, it will be seen that some 20 per cent. of the pottery and allied firms have changed over from raw coal to town gas firing, so that there remains a great deal of scope for the future before smoke is completely eliminated.

As mentioned, the carbonisation of coal affords additional benefits in that coke and by-products result, and it represents the peak of present technical achievement. This is very well illustrated simply by stating that, of every 100 tons of coal which enters a gasworks, at least 80 tons of the heat energy of the fuel is obtained in one form or another, by way of heat units in gas, coke, benzole, tar, etc.

Should it transpire that coke becomes universally accepted as a basic smokeless fuel, it is not beyond the realms of possibility that the demand would exceed the ability of the country's gasworks to supply it, and the production of this coke might be carried out at the pithead. If such a project should materialise, and since the North Staffordshire district possesses a large number of collieries, surplus coke-oven gas would be available in fairly large quantities. Having in mind the potential industrial requirements of our staple trade, most of this surplus gas could be distributed and applied locally with very beneficial results, and would accelerate the trend towards domestic and industrial smoke abolition.

DRYING

The heat requirements of the ceramic industry are by no means limited to the firing of ware, a considerable volume being used for process work, of which drying is the most important. Until recent years, practically all this drying has been carried out by steam—either live or exhaust—in rooms or chambers specially set apart for the work. Few, if any, manufacturers have accurate costs of this process, partly due to the wide variations in moisture content of the clay at different stages of " making " and to the lack of instruments for measuring the heat supplied to the drying plant.

The raw clay taken from the filter press has a moisture content, mainly in the form of added water, of 20 per cent. or more. This must be reduced in some cases to, approximately, 6 per cent., in other cases to 1 per cent., according to the ware being produced. Further problems arise due to the absorbent properties of the clay when in a relatively dry condition and the fact that at the " dipping " stage moisture is absorbed from the liquid glaze.

Gas has not only been successfully adopted for heating existing drying chambers, but also as the heating medium for new drying plant, including conveyor and rotating chamber types in which the process is more or less continuous, and has considerably reduced the cost of operation and the time required for drying. In the case of cups, saucers, plates, etc., produced in or on moulds, further economies have been effected in the longer life of moulds and the reduced number required due to the shortened period of drying.

As figures of costs with solid fuel are not available it has not been possible to work out comparative costs for gas, but the following details give an indication of the results obtained in various types of gas-heated drying plant.

	Weight of clay	Initial moisture	Final moisture	Gas/ton dried
	Tons	Per cent.	Per cent.	Cu. ft.
Drying clay from filter press, chamber-type dryer with bar burners below stillage.	9	20	4	1,400
Ditto, chamber-type dryer with radiant tube burners in stillage.	11	20	4	1,200

	Cups dried per 8 hr. day	Gas consumption per day	Gas consumption per dozen cups
	Doz.	Cu. ft.	Cu. ft.
*Drying cups in moulds in semi-continuous dryer with gas-heated air circulator.	275	1,300	4·72
*Drying dipped cups in continuous radiant-heat dryer, gas heated.	240	1,600	6·6

* It is claimed that by these two methods of drying the time required for making and drying is reduced from two days to one hour.

FRIT MELTING

Town gas is being used in both rotary and batch melters for the production of the frits required for glazes and enamels used in the ceramic and vitreous enamelling industries. It has been our experience that melting costs in the rotary melters are higher than the batch type, although the rotary type cost less for maintenance and, generally speaking, can be brought into effective operation in shorter time.

Gas consumption per pound of frit " off " varies considerably according to the type of frit and the condition of the melting furnace. With the smaller rotary types up to a length of 5 ft., the consumption for a good quality frit averages approximately 12 cu. ft. per lb. of frit " off ". The batch type melters are usually about 10 ft. to 12 ft. in length and 2 ft. 3 in. to 3 ft. 3 in. wide, single burners being employed in the narrower ones and two burners in those with a width above 2 ft. 6 in. Figures as low as 8·43 cu. ft. of gas per lb. of frit " off " have been recorded for good quality frits in newly-built furnaces, rising to 10 to 11 cu. ft. per lb. as the interior brickwork deteriorates.

The following comparison of fuel consumption on coal-fired and gas-fired melters of identical capacity show the economy of gas in this connection.

	Coal-fired frit kiln	Gas-fired frit kiln
Weight of charge " on " . . .	9 cwt.	9 cwt.
Melting time	2·5 hr.	2·5 hr.
Therms per melt . . .	72·8	43·9

This is equivalent to a reduction in fuel consumption of 41 per cent.

2. The Trend of Fuel Economy in the Ceramic Industry

By T. LOCKETT, O.B.E. and L. BULLIN, B.SC.

In the ceramic industry the fuel requirements can be placed into three main categories :—

(1) Steam raising.
(2) Ware drying.
(3) Ware firing.

The steam raising problems are very similar to those of most other steam users. Steam is still the cheapest motive power for the main driving shafts of the factory, but there is a distinct tendency now for factories gradually to reduce the load on the boilers and use electric motors for individual machine drives where the extra convenience justifies the cost : in fact, one modern pottery factory built eleven years ago relies entirely for motive power on electric motors, while the clay drying and space heating is done by the hot air drawn from the tunnel kilns, thus utilising a 24-hour waste-heat supply to the full. There are indications that all or part of this procedure will be adopted by many ceramic firms in the next ten years as more new tunnel kilns are installed.

Ware drying is undergoing a complete revolution, although there is some divergency of path in the direction of the changes. Until recently practically all clay was dried slowly in steam-heated stoves where there was inadequate control of heat, and where the continuous excursions of the operative in and out of the stove had a very detrimental effect on health. Recent improvements have made use of infra-red drying (mainly town gas) either with or without forced convection, or by the use of closed revolving stoves heated by steam or gas, where the heat is utilised to the best advantage and efficient insulation prevents undue heat at the working bench. By these means drying times have been reduced from hours to minutes, and the quality and uniformity of the ware has improved.

Research is still going along on the new lines, and without doubt the whole industry will have taken advantage of these improvements within a few years, with a consequent large saving of fuel and a radical improvement in the health of the worker.

The ware firing process is, however, the most important from the angle of fuel requirements. In most factories oven or kiln firing accounts for from 70 per cent. to 90 per cent. of the total fuel used.

Fuel also means more to this industry than to probably any other. The siting of the main part of the industry by Wedgwood and his contemporaries in N. Staffs was mainly due to the very suitable high-volatile coal found there. The whole of the craft in all its many branches has been built up around the successful firing of the ware.

The fuel and the firing process are the hub and bearing upon which the whole process of production depends. If this process goes out of gear the firm goes out of business in a very short time, and such happenings have been quite frequent in the past. It is small wonder, therefore, that those responsible for the production of ceramic wares have been very cautious in changing any of the details of this process, let alone any radical change in the method of firing ; and so for nearly 200 years the old intermittent oven or kiln has carried on practically unchanged.

The first successful tunnel kiln for the continuous firing of goods was built in this country in 1912, but it was not until about 1925–28 that this revolutionary change made a wider appeal and a few brave manufacturers took their courage in both hands and pioneered into the comparatively unknown dangers of the tunnel kiln. There were many difficulties which had to be overcome and some of the large firms had serious losses for a time, losses that would have put smaller firms out of business, but the tunnel kiln won through and by 1939 was an established fact for the firing of most types of ceramic ware.

The reasons for success were several :—

> It was proved that as good or better quality finish could be obtained for the highest grade goods, and there was greater uniformity throughout the products. It lent itself admirably to mass production of utility or low-priced lines.
>
> It made and kept the *tempo* of production for the whole factory, and the continuous flow of finished goods made for greater efficiency of working. Working conditions for the operatives were made very much easier, and labour costs were considerably less, while last but by no means least, the continuous firing process showed very considerable fuel savings when compared with intermittent oven firing.

It is possible to forecast with some degree of accuracy the progress that will be made in the next few years. The advance of scientific method into the industry during the last ten years has been considerable, and there is now a feeling of confidence in the continuous firing process.

The desire to change over from intermittent oven firing is so great that unless there is careful planning of all essential requirements for the next few years there is a danger of considerable chaos.

Unfortunately there is no royal road to standardisation in the building of these kilns. The kiln size and cross section must bear a relationship to the output of the factory and the type and size of ware being produced ; while the length in many cases has to be governed by the space available.

The type of fuel is often dependent on the location of the factory for supplies and on the prices ruling in that district for the various fuels. In the reverse direction the type and design of kiln is very dependent on the fuel to be used.

These considerations show that tunnel kilns must in most cases be " tailor made to measure " not " ready made in stock sizes."

These facts rather slow down the speed of construction, but at the same time they will enable considerable progress to be made in design, for the builder will be able to include new modifications and improvements on later kilns, as the results of research and experience become manifest.

As we have already indicated, the most important factor to decide before a tunnel kiln is planned is that of the type of fuel to be used. In this choice there are two major considerations :—

(*a*) The suitability of the fuel for the particular type of ware to be fired.

(*b*) The cost of the fuel per therm.

This choice has probably never been more difficult than it is at the present time, so that some consideration of the relative merits of different fuels may be worth while.

(1) *Coal.*—This is probably the cheapest of all the fuels which can be used, but in the raw state it is not suitable for firing white ware kilns, though in the form of coal " peas " it is being used with some success in automatic stokers, for the firing of bricks in tunnel kilns.

(2) *Pulverised Coal.*—This is being used successfully in several kilns. It is more suitable than raw coal since it can be carried through pipes and treated very much like a gas. It has a lower gross cost than most fuels, but the difficulty of the fly-ash is a rather severe handicap. It is only possible to use it for firing clay ware and then the ware itself must be sealed off in saggars from the effects of the ash, except in the case of bricks or refractories where " flashing " is not of serious consequence.

(3) *Producer Gas.*—Hot raw producer gas was a favourite fuel in the early days of tunnel kilns, using coke or anthracite as fuel. It had a relatively low gross cost and the suction producers could be built alongside the kiln as an integral part of the structure. The advent of the multi-burner kiln, however, meant using clean gas and the suction producer gave way to the pressure producer.

The steep rise in price of coal, coke and anthracite during the last five years compared with the relatively small increase in price of fuel oil and town gas has made the gross cost of producer gas as high or higher than these cleaner and less troublesome alternatives. At the present time, therefore, manufacturers are anxious to scrap their producer plant and change to one or other of the alternatives as they become available in supply.

(4) *Fuel Oil.*—The lead which the Government has given recently to the use of fuel oil should act as an incentive for the use of this fuel for tunnel kilns. It is an admirable fuel for those firms outside the reach of cheap town gas. Its price is now very competitive and it has all the necessary qualities needed in continuous firing, viz., cleanliness, uniformity of calorific value, ease of storage, ease of control and a high flame temperature. Increased fire risk is the only hazard, and care in designing the plant can minimise this drawback.

The only factor which has kept this fuel from being more popular in the past was its price. The cost, including tax, kept it just outside the competitive price range in most localities ; while the fear of increased taxation deterred manufacturers from using it as an essential fuel. The present reduced price and the relative increase in costs of other fuels during the war period, has now brought it back to a competitive figure, and there is no doubt its use will increase if there is some guarantee of price stabilisation.

(5) *Town Gas.*—This is undoubtedly the most popular fuel at the present time for tunnel kiln firing.

In the Stoke-on-Trent area over 80 kilns are using town gas and burning over 2,200 million cu. ft. per annum.

It is a very suitable fuel for either muffle or direct fired kilns. It is clean, very low in sulphur content, uniform in quality and regular in supply. Of all the gaseous fuels it is most easily adaptable to automatic control for the maintenance of constant temperature.

Its popularity has been further enhanced in the Stoke-on-Trent area by its comparatively low cost per therm. Even before the war the price of town gas made it a competitive fuel for all except the largest factories.

Since then, however, coal, coke and anthracite have more than doubled in price. From 1940 to September 1946 town gas has maintained a rise of only 12½ per cent., but this has been raised from October 1st, 1946, to between 29 per cent. and 38 per cent. over 1939 prices.

(6) *Electricity.*—Electricity as a source of heat for tunnel kilns is a comparatively new development. The late Bernard Moore was experimenting with electrically-fired decorating kilns as long ago as 1907 but it was not until 1927 that his son B. J. Moore and A. J. Campbell installed the first commercial electric decorating kiln at Messrs. Mintons, Ltd. This decorating or "enamelling" process only requires a temperature of about 700° C. so that the application of electric elements to stand up to these conditions was not difficult. The kilns were a great success and by 1938, 25 of these electric enamel kilns of different designs were in operation in the N. Staffs. area, using over 10 million kWh per annum.

In 1939 Wedgwoods installed the first electric commercial high-temperature tunnel at their new Barlaston works, firing earthenware biscuit and glost ware up to a maximum temperature of 1140° C.

This kiln is of the double track counter-flow type, the clay and glost ware travelling in opposite directions on adjacent parallel tracks in the same tunnel. By this means there is a considerable amount of heat exchange at the two ends of the tunnel and the area of outside walls, where radiation and convection losses take place, is considerably reduced.

This kiln is working satisfactorily and is exciting very keen interest throughout the industry on account of its high thermal efficiency, ease of control and the good quality of ware produced.

By 1942 three high-temperature glost kilns were operating on electricity and the kWh consumed had risen to over 14 million per annum. Then the concentration of factories came along and the load dropped to 10 million again by 1945. At the present time, besides 22 electrically-fired kilns in operation, there are a further 19, including 12 for high-temperature biscuit or glost firing, on order or under construction in the N. Staffs. district.

Let us look at the general considerations which prevail in determining the adoption of electricity as the fuel.

(*a*) *Fuel economy.*—A higher thermal efficiency in the kiln itself can be achieved with electricity than with any other fuel. This is arrived at in three main ways :—

(1) Because an electrically-fired kiln lends itself better to heavy insulation than any other type, so reducing the generally high radiation and convection losses from walls and roof.

(2) In the electrically-fired kiln there is no air necessary for combustion and the exhaust gas and excess air losses are cut out. Only in the biscuit tunnel is a small amount of air needed to take away the free and combined water from the clay and the small volume of CO_2 from any carbonaceous matter in the body.

(3) The atmosphere of the electric kiln being perfectly clean there is no need for saggars or boxes in which to place the ware. All the goods are placed quite open and the supports can be on more slender lines than for

other forms of firing, so that a very high packing density for ware can be achieved and the ratio of weight of ware to weight of supports can be considerably increased.

It is largely because of this last item that the electrically-fired tunnel has shown a better ware efficiency figure than the town gas, producer gas or oil fired kiln. An example may make this clearer :—

> In the earthenware glost tunnel kilns, gas-fired, the ratio weight of ware/weight of supports is approximately 1 : 3. In the electrically-fired glost kiln it is nearer 1 : 1. This means that if the *overall efficiency* of the electric kiln is 1½ times that of the gas-fired, then the *ware efficiency* will be three times as great.

(*b*) *Reduction in labour costs.*—Labour costs are low and the work is comparatively light. With the car tunnel, sufficient cars can be placed during the day shift to last 24 hours, but with the conveyor type and the circular decorating kiln, shifts have to be worked.

(*c*) *Simplicity and precision of control.*—It is undoubtedly the easiest kiln to control and most kilns are fitted with automatic control which keeps maximum temperatures to within 2° or 3° C. of standard. The fireman's job becomes a matter of routine rather than skill. Because of this precision the ware is very uniform in porosity, size, colour and quality.

(*d*) The atmosphere of the kiln is very clean and free from sulphur, so that there is no contamination for the most delicate colours. The operation of the kiln is also essentially clean, giving the possibility of a very clean and dust-free factory.

The electrically-fired enamel tunnel kiln is now firmly established as a standard method but the high-temperature electric kiln is still in its infancy. It is, however, developing rapidly—how far that development will proceed it is difficult to say, but there are several main lines along which research is moving :—

> (1) *The improvement of the heating elements.*—It is essential to have a resistor which will stand up to 1300° C. or 1350° C. for a considerable period if the firing of the majority of white-ware products is to be undertaken. Considerable work has been done along these lines recently and a suitable high-temperature metallic resistor should be developed on a commercial basis as soon as possible if the wider field is to be opened to the electrical kiln.
>
> (2) *Equalisation of temperature in the kiln.*—If ware is to be fired quickly and uniformly there must be more than radiation to transfer the heat. In the open gas-fired kiln the flow of the gases produces convection currents which give a high transference of heat and helps to increase the uniformity of firing. In electrical firing there is very little convection heating. Research is now being carried out to improve this air circulation as a means towards achieving greater uniformity of temperature throughout the setting.
>
> (3) *The conveyor kiln.*—If a steel band conveyor can be used in place of cars, many new possibilities can be opened up. Placing is simplified. The main structural supports for the ware can be eliminated and the ratio—ware : supports can be increased still further with consequent

increases in thermal efficiency. The kiln construction is simplified and capital costs reduced. The units can be small and suitable for the small manufacturer who has limited room and capital. The uniformity in heating can be improved and the speed of firing increased. On the other hand, the kiln will need continual 24 hr./day attention and the cost and maintenance of the belt will no doubt be high.

(4) *Improvement in kiln furniture.*—The introduction of a high-temperature-resistant steel structure in place of the present refractory setting would greatly improve the efficiency, not only because of the better packing of ware which would be possible, but also because of its own low specific heat.

(5) The introduction of bodies and glazes suitable for rapid firing, which will develop strength and crazing resistance without the long soaking fire necessary for most types of biscuit at the present time.

The Electricity Department of Stoke-on-Trent, has sought to assist development principally by affording supply at rates which have been at a level as low as could reasonably be expected in face of the rising trend of costs.

It would appear from the data available that in terms of thermal efficiency and of fuel consumption the electric tunnel oven either for biscuit or glost shows to advantage compared with the gas-fired tunnel, which is itself a very considerable advance on the intermittent oven.

When the comparative costs of the two fuels are considered there is little to choose between them and it seems probable that there will be a parallel increase in both types of kiln in the next few years, the one or the other being built where the particular merits of one fuel swing over the scale, because of the type of ware to be fired or the particular site of the kiln or the location of the factory.

It is to be hoped that the comparative utilisation costs of the two fuels can be kept closely comparative for a few years, for the healthy and friendly rivalry will be good for both industries, and will tend to improve the characteristics of both types of kiln more rapidly than would be done by unilateral development. In both cases there is much data yet to be obtained and made generally available and there is need of much further independent research.

The trend of fuel economy in the ceramic industry then seems to be clear :—

The intermittent ovens will gradually become obsolete, just as they have already become obsolete in America. The industry will fall into line with the present national trend to use manufactured fuels in place of raw coal.

Town gas, electricity and fuel oil will be used as standard methods of heating in the new tunnel ovens and the atmosphere of the industrial area will benefit accordingly.

Tunnel kiln design will undergo considerable change. The general tendency will be to use kilns of smaller cross section running at faster speeds with higher placing densities than at present possible. Temperature, draught and atmosphere control will be automatic, so that a still greater uniformity in fired ware will be possible.

Thermal efficiency of the kiln will show progressive improvement as the ceramic research worker, the fuel technician and the kiln builder co-operate in constructing new kilns.

COMPARATIVE FUEL COSTS IN FIRING TUNNEL KILNS
(*October* 1946)

	Net cost per therm pence	Gross cost per therm pence
(1) Coal peas or slack at 42*s*. a ton	1·80	2·12/2·52
(2) Pulverised coal at 42*s*. a ton	1·80	2·62
(3) Producer gas—		
Hot raw gas from small producer (30 ton/wk.)		
Coke at 65*s*. a ton	3·63	4·34
Anthracite at 85*s*. a ton	3·95	4·66
Cold clean gas from bituminous coal beans at 42*s*. a ton. Large pressure producer (100 tons/wk.).	2·65	3·59
(4) Fuel oil at 7¼*d*. a gallon, less ¾*d*. discount for deliveries over 1,000 gallons.	3·65	4·05
(5) Town gas (Stoke-on-Trent)—		
10/15 million cu. ft./quarter	3·68	3·68
Over 15 million cu. ft./quarter	3·58	3·58
(6) Electricity (Stoke-on-Trent)—		
Enamel or decorating kilns 0·582d/kWh.	17·04	17·04
Glost or biscuit kilns 0·510d/kWh.	14·95	14·95

3. Heat Requirements in Pottery Firing

By A. DINSDALE, M.SC., F.INST.P.

INTRODUCTION

The pottery industry embraces a wide variety of products and each of these requires its own peculiar firing technique so that it would be impossible to deal with each of them adequately within the scope of a short paper. It is proposed, therefore, to confine such observations as are made to the most commonly met and familiar type of ware, namely, general earthenware. Most of the fundamental principles of heat transfer and utilisation will be applicable with but slight modification to other sections of the industry. The specific purpose of the paper is to show what the heat requirements of the ware are and to indicate roughly how efficiently they may be met in several different methods of firing. Biscuit and glost firing only will be considered, and since the heat requirements are different they will be dealt with separately.

HEAT REQUIREMENTS IN BISCUIT FIRING

The first firing of clayware after the making of the article is known as the biscuit firing. In this process the ware is dried, undergoes certain physical and chemical changes, and thereby acquires the rigidity and resistance to fracture necessary to give it the required degree of permanency in use. Three stages in the firing are generally recognised.

(*a*) A " water-smoking " or drying period. During this period, which may be assumed to cover the time from the start of the firing to the time when the temperature of the setting reaches 250° C., all the mechanically-held water is driven off from the ware and is removed from the oven in the exhaust gases. For the purpose of computing the heat requirements it is assumed that for the intermittent oven the average temperature of the flue gases during this period is 150° C. For the tunnel oven, of course, the actual temperature of the gases leaving the oven must be used.

(*b*) A period during which the temperature of the setting rises from 250° C. to 850° C. During this period the clay undergoes structural changes ; the clay molecule is broken down and the combined water is released, a considerable amount of heat being used up in this process. In addition any carbonaceous matter present in the clays is burnt off; the amount of heat thus given up, although it may often be considerable in the heavy clay industry, is generally small in the case of pottery, and is neglected in the present paper.

(*c*) The period from 850° C. to the end of the firing, generally known as the vitrifaction or finishing period. During this period the main change in the nature of the ware is a progressive decrease in the porosity until the required degree of vitrification is reached.

It will be clear that a proportion of the heat supplied to the ware will not be recoverable on cooling, since it has been used up in producing the necessary physical and chemical changes, and there is a sense in which it is true to say that this irrecoverable heat is the only heat requirement of the ware. For tunnel ovens, given perfect heat recovery and perfect insulation, the heat input would only be that required to supply this irrecoverable heat.

A picture of the relative magnitude of the various amounts of heat may perhaps best be gained by working a concrete example, based on a weight of 100 lb. of ware as placed in the oven. This will be assumed to contain 1 per cent. mechanical water, and 5 per cent. combined water on the dry basis. To simplify the calculations a placing temperature of 0° C. will be used.

The heat required for the drying is made up as follows:—

Heat required to raise temperature of 1 lb. of water to 100° C.	180	B.Th.U.
Latent heat of water at 100° C.	970	,,
Heat required to raise temperature of 1 lb. of water vapour from 100° to 150° C.	40	,,
Total	1,190	,,

Before the heat required to fire the dry ware to the finishing temperature which is generally about 1100° C. for biscuit earthenware, can be calculated it is necessary to know the overall specific heat including the heat taken up by the chemical and physical changes. This may be arrived at in several ways, but only one method is described here. This method makes use of results published for various clays and for certain fired materials. The body is assumed to consist of a mixture of pure clay substance, and substances whose specific heat are not greatly different from fired silica brick. The interval specific heats of a typical clay and of the silica brick are shown in Table I.

TABLE I

INTERVAL SPECIFIC HEATS OVER THE RANGE 0°–t° C.

t ° C.	Clay substance	Fired silica brick
100	0·380	0·198
200	0·390	0·206
300	0·430	0·214
400	0·448	0·222
500	0·484	0·229
600	0·557	0·236
700	0·520	0·242
800	0·501	0·248
900	0·502	0·253
1000	0·497	0·259
1100	0·502	0·264

The amount of clay substance in the body may be calculated from the combined water content. For the pure clay substance, $Al_2O_3 . 2 SiO_2 . 2H_2O$, the water content is 13·95 per cent., so that a body containing 5 per cent. combined water has a clay content of $\frac{5 \times 100}{13 \cdot 95} = 35 \cdot 8$ per cent.

The specific heat of the clay substance over the range 0° to 1100° C. is 0·502 (Table I) and that of the remainder of the body 0·264. Thus the specific heat of the body is

$$(0 \cdot 358 \times 0 \cdot 502) + (0 \cdot 642 \times 0 \cdot 264) = 0 \cdot 349.$$

Hence the amount of heat required to fire 99 lb. of dry body is

$$99 \times 1{,}100 \times 1 \cdot 8 \times 0 \cdot 349 = 68{,}400 \text{ B.Th.U.}$$

The sensible heat at the maximum temperature, which is the same as the amount of heat which would be given up on cooling, is

$$94 \cdot 05 \times 1{,}100 \times 1 \cdot 8 \times 0 \cdot 264 = 49{,}200 \text{ B.Th.U.}$$

Thus, the amount of heat which has been used up in the firing and which is not recoverable on cooling is

$$68{,}400 - 49{,}200 = 19{,}200 \text{ B.Th.U.}$$

This irrecoverable heat represents about 28 per cent. of the heat required to fire the dry body.

The heat requirements in B.Th.U./100 lb. for biscuit ware as calculated above for this particular example may be summarised as follows :—

Heat for drying
→ 1,190

Total heat supplied
69,590

Irrecoverable heat
→ 19,200

Heat given up on cooling
→ 49,200

HEAT REQUIREMENTS IN GLOST FIRING

After the first firing, the biscuit ware is dipped in glaze and fired again, this being known as the glost firing. The heat requirements in glost firing differ from those in biscuit firing in that the amount of irrecoverable heat used up is much smaller in relation to the total heat required to fire the ware to the maximum temperature. We may illustrate this by again working out an example. For thin general earthenware the weight of glaze is about 10 per cent. of the weight of the body, although for thicker articles it is considerably less. We consider, then, 100 lb. of body and associated with it 10 lb. of glaze, the mechanical water generally being negligible. The amount of heat required to fire the ware to a temperature of, say, 1100° C. consists of three parts, viz. :—

(*a*) The sensible heat in the body. If the specific heat be taken as 0·264, the quantity of heat is

$$100 \times 1{,}100 \times 1 \cdot 8 \times 0 \cdot 264 = 52{,}280 \text{ B.Th.U.}$$

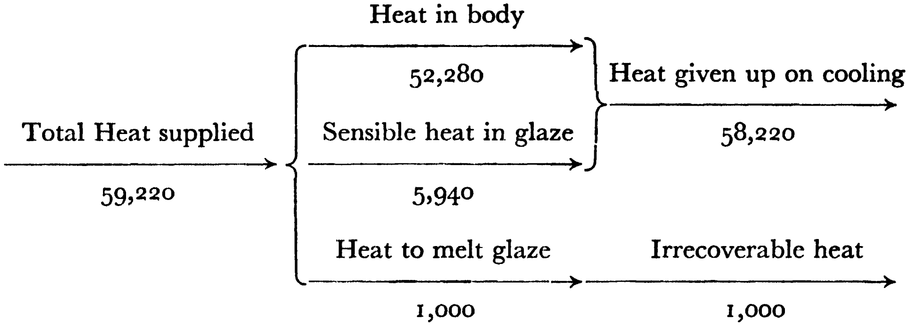
(*b*) The sensible heat in the glaze. The weight of the glaze is 10 lb. and the specific heat may be taken as 0·30, so that the quantity of heat required is

$$10 \times 1{,}100 \times 1 \cdot 8 \times 0 \cdot 30 = 5{,}940 \text{ B.Th.U.}$$

(*c*) The heat used up in melting the glaze. This will generally be of the order of 100 B.Th.U. per lb. of glaze, so that in the present example the irrecoverable heat is

$$10 \times 100 = 1{,}000 \text{ B.Th.U.}$$

The total heat required is 59,220 B.Th.U. of which 58,220 B.Th.U. would be given up on cooling. The irrecoverable heat used up is thus only about 2 per cent. of the total heat, as compared with 28 per cent. for the firing of the clay ware. The heat requirements for glost firing may be summarised as follows :—



HEAT UTILISATION BY VARIOUS FIRING METHODS

The firing of pottery is carried out in two main types of furnace, the intermittent oven and the tunnel oven, and the two differ fundamentally. With the intermittent oven, all the heat contained in the goods at the finishing temperature is lost to the atmosphere on cooling, whereas with the tunnel oven a large proportion of it is recovered and passed on to the incoming ware. Intermittent ovens are coal fired, while tunnel ovens use producer gas, electricity or town gas, the latter being by far the most common.

TABLE II

COMPARATIVE EFFICIENCIES OF SOME OVENS FIRING EARTHENWARE

	Biscuit			Glost		
	Coal-fired intermittent oven	Town gas open-flame tunnel oven	Electric tunnel oven	Coal-fired intermittent oven	Town gas muffle tunnel oven	Electric tunnel oven
Percentage thermal efficiency :						
For ware	5·5	10·1	52·5	1·6	14·3	40·6
For total setting	16·4	28·9	86·0	9·6	62·4	89·5
Fuel consumption, therms :						
Per ton of ware	262	159	38·7	716	78	27·3
Per ton of total setting	76·8	44·4	19·1	119	18	12·3
Contraction trial ring*	35	27	36	12	9	14

* Eighty per cent. of the setting was fired to this ring value, or harder.

An indication of the relative efficiency of utilisation is given in Table II, which shows the thermal efficiency and fuel consumption for some typical biscuit and glost ovens. It should be noted that these results apply to one oven only, and to the conditions operating at the time the test was made, so that great caution must be exercised in drawing general conclusions from them. In particular, the contraction trial ring values indicate that the setting was not fired to the same degree of hardness in all cases.

Bearing these considerations in mind, the following conclusions may be noted :—

(*a*) Since it has been shown that the basic heat requirement for the ware is only about 30 per cent. of the thermal efficiency figure for the ware in the case of biscuit and only about 2 per cent. in the case of glost, it is clear that even with the highest efficiency shown there is still considerable scope for improvement.

(*b*) The gas-fired tunnel oven is more efficient than the intermittent oven.

(*c*) Electricity shows a much higher efficiency of utilisation than gas, owing to the following factors, among others :—

(i) Low flue-gas losses, since no air is needed for combustion, and the only flow of gases is that required to maintain a clean atmosphere and accomplish the heat exchange.

(ii) Cleanliness, resulting in the use of open setting without saggars.

(*d*) It has to be borne in mind that the above considerations take no account of the efficiency of generation of these fuels. When this is considered the picture takes on a different aspect.

(*e*) It will be seen from Table II that much of the advantage of electricity over gas so far as the ware is concerned is due to the higher setting density which can be obtained by using open setting as against saggars. Thus, an extremely important factor so far as the future trend is concerned is the possibility of firing by town gas without using saggars. If this should prove possible, it would double the efficiency of gas firing, and completely alter the present situation.

4. Fuel Utilisation and Economy in the Refractories and Heavy Clay Industries

By E. ROWDEN, B.SC., D.I.C., F.R.I.C.

INTRODUCTION

The refractories and heavy clay industries are concerned with the manufacture of various types of products, each of which has its own firing requirements, i.e. maximum temperature of firing, method and rate of heating, kiln atmosphere, etc.

The main products, broadly speaking, comprise :—

(1) *Refractory Materials :* fireclay bricks and shapes ; diatomaceous and refractory insulation products ; silica bricks and shapes ; and chrome, magnesite and dolomite high-temperature refractories.

(2) *Building Materials :* common bricks ; facing, engineering, rustic, multi-coloured and blue bricks ; red, multi-coloured, blue and sand-faced roofing tiles and ridge tiles ; floor quarries ; salt-glazed pipes ; agricultural land drains ; hollow building blocks, etc.

The complexity of the industry can be gathered from the fact that each clay differs and requires its own firing treatment, which is also affected by the process of manufacture, so that, for any one of the above products, the firing treatment from works to works, although similar in certain respects, differs appreciably. For the different products maximum firing temperatures range roughly from 850° to 1200° C. for common building bricks (more usually 950°–1050° C.); 1100°–1400° C. for fireclay goods; 1150°–1250° C. for salt-glazed pipes; 1400°–1450° C. for silica goods; 1420°–1500° C. for basic refractories, etc.

Intermittent kilns are largely used in most branches of the refractories and heavy clay industries, except for the firing of building bricks where continuous kilns predominate. Continuous kilns are, however, quite widely used. Nearly all the common building bricks now produced and about 50 per cent. of the output of fireclay goods in this country are fired in this type of kiln as well as a proportion of certain of the other products. However, intermittent kilns are often considered desirable for the firing of special shapes and blocks, particularly of large sizes; for certain classes of products; and, for use on those works which have either a small output or a variable output of several different products. Thus silica goods, salt-glazed pipes, certain types of red roofing tiles and blue, brindled and multi-coloured bricks and roofing tiles, etc., are amongst the products generally fired in intermittent kilns since satisfactory methods of firing in continuous kilns have not been fully developed. The intermittent kiln proves more amenable where special conditions of firing, of cooling or of atmosphere are required.

Intermittent kilns are generally of the round or rectangular down-draught type, coal fired on to grates or fireholes round the periphery or, in the case of rectangular kilns, down each side or at the ends. Their disadvantage is that the fuel consumption is high as compared with that of continuous kilns. A high percentage of the heat generated from the fuel is lost (1) in the waste combustion gases exhausting to the stack and (2) in the hot goods at the completion of firing, during the cooling period. Some recovery of heat from these two sources is possible, but the maximum effect is obtained only when the continuous system of firing is adopted.

Continuous kilns are of various types and can be broadly divided into barrel arch kilns, chamber kilns and car tunnel kilns. For common building and facing bricks all three types of kilns are used. The most commonly used is the top-fired Hoffmann kiln, in which slack coal, usually ½–1 in. and below, is fed through a series of small holes in the kiln crown down amongst the bricks. Side-fired Belgian type kilns, in which the coal is charged through the wicket on to a grate extending across the chamber, are also used, often for firing to higher temperatures up to 1200° C. Both these kilns are of the barrel arch type with sixteen or more chambers but without division walls between chambers. Chamber kilns of the Staffordshire, Super Staffordshire, Lancashire, etc., types are also employed. These are of the transverse arch type, with division walls between chambers and are generally top-fired with ½–1 in. slack either amongst the goods or on to a fender at the beginning of each chamber. The car tunnel kilns, 350–400 ft. long, are generally either side-fired with mechanical stokers using graded coal or, in the case of the Monnier kiln, top-fired with small coal down amongst the goods.

For fireclay goods, the Belgian type of kiln is largely used for firing to temperatures of 1250°–1300° C. and sometimes to higher temperatures. For firing to the higher temperatures chamber and car tunnel kilns are usually employed. The chamber kilns are either producer-gas fired or direct coal fired on to either four or more grates per chamber or on to a grate extending across the chamber. Good quality coal is required both for producer and for direct firing. Chamber kilns, although having a higher fuel consumption than the Belgian type kiln because of the presence of division walls between chambers and maybe of complicated under-floor flues, have the advantage that specials may be fired in them and that chambers may be heated up to definite temperatures and soaked at those temperatures as long as desirable according to the requirements of the ware. These advantages more than counterbalance the increased fuel consumption. The car tunnel kilns for burning refractories are usually fired with hot raw producer gas generated from bituminous coal in static or mechanical producers. However, side firing with mechanical stokers may be employed for temperatures up to 1300°–1350° C.

CONSUMPTION OF FUEL

The refractories and heavy clay industries at the present time consume approximately 2–2½ million tons of solid fuel per annum. Large increases of production are to be expected in the building brick, roofing tile, salt-glazed pipe and related building materials sections of the industry, which during the war operated at very low outputs. Fuel consumption will, therefore, increase. Pre-war the consumption of coal for the kiln burning of common bricks, when the output was about 7,000 million bricks per year, was about 2½ million tons per annum. A total fuel consumption for the heavy clay and refractories industries of the order of 4 million tons of solid fuel per annum is to be expected when the works are in full production again.

Fuel is used for the following purposes : to fire the kilns ; to heat the dryers used for drying clay or goods prior to firing in the kiln ; to fire the boilers ; and for power. The kilns are mainly fired with coal but some continuous kilns are fired with hot raw producer gas from bituminous coal and a few with producer gas generated from coke. Dryers are of different designs, namely hot floors or sheds, chamber dryers and car tunnels dryers, the latter two types being the more efficient. The hot floors or sheds are mainly heated by coal fires or by exhaust steam supplemented with live steam, although live steam alone is employed on some plants. Chamber and car tunnel dryers are heated with live steam, exhaust steam, hot air drawn off from the kilns, hot air obtained by direct heating with solid fuel or steam, or by two of these heating media combined. The boilers are fired with solid fuel. The steam is generally used for power purposes and the exhaust steam employed for drying purposes. Occasionally where steam is not used for power, the boiler is employed solely to provide steam for drying. Again, on a few of the smaller works recirculating pressure hot water systems are employed.

For power, steam and/or electricity are mainly used but Diesel oil is sometimes employed and very occasionally anthracite in conjunction with a gas producer and gas engine. In the manufacture of common building bricks, those bricks made by the stiff-plastic and semi-dry press methods, equivalent to 64 per cent. of the total output of common bricks in 1938, are set direct in the kiln without drying. For this reason the making plant when employing these methods of manufacture is mainly driven by purchased electricity. On the other hand, wirecut and hand-made common bricks, which in 1938 comprised 30·6 per cent. and 2·1 per cent. of the total output of common bricks, are plastic made and require drying prior to setting in the kilns. Consequently boiler plant is more often than not utilised, and the exhaust steam used for drying purposes. This is not essential, however, since at some wirecut works electricity is used for power, and other sources of heat than steam are used for drying, more often on chamber or car tunnel dryers, e.g. hot air drawn off from the kiln. In the salt-glazed pipe section of the industry boilers are employed at practically all works. In the refractories industry purchased electricity is often used as a supplement to steam power. The amount of electricity consumed by the larger firms at present exceeds 50 million units per year ; the total consumption probably exceeds 100 million units per annum.

QUALITY OF THE FUEL USED

The quality of the fuel necessary in the refractories and heavy clay industries is dependent on the type of product, the type of kiln or the type of plant on which it is consumed. Low quality fuels are utilised to quite a large extent but there are definite exceptions where its use is not possible. Large coal, graded coal or high quality coal is necessary generally on the more modern and efficient units of plant such as : on producer-gas fired continuous car tunnel or chamber kilns ; on grate-fired continuous kilns either of the car tunnel, chamber or Belgian type, particularly where firing to high temperatures ; on intermittent kilns after the initial heating stage up to 600°–800° C., again especially when firing to high temperatures as in the case of silica, sillimanite, basic and fireclay products ; and on stoker-fired and highly loaded boiler plants.

Low grade and substitute coals are, however, widely used. For the firing of common building bricks in top-fired continuous kilns, rough and fine slacks are generally employed, fine slack below ½–1 in. being mostly preferred. As top-fired kilns of the Hoffmann and related types are mainly used for firing common bricks, under normal peace-time conditions of output the tonnage of this type of fuel consumed is quite considerable. On some four works, firing has been carried out for several years with anthracite duff on top-fired kilns fitted with mechanical feeders, while washery silt is being used on at least two works. At one of these works 100 per cent. of silt is being used for firing bricks made from a carbonaceous clay to a temperature of 900°–950° C. ; the other works is utilising a mixture of 60 per cent. of silt with de-dusted slack. Although low-grade coals may be used in certain cases on intermittent kilns for firing to low or medium temperatures or up to temperatures of 600°–800° C., their use at higher temperatures gives rise to ash or clinkering troubles, to difficulties in obtaining the maximum temperature, and to lengthening of the time of firing so that not only is the fuel consumption increased considerably but the quality of the product may be affected.

On a large number of works in the industry, the fuel used for boiler firing comprises one or more of the following : rough slack, small graded slack, fine slack, clay-hole coal, open-cast coal and in a few cases coke, coke ballast and coal with a proportion of washery silt. Coal-fired drying sheds are often heated by means of fine slack, reject coal from belt pickings and, in a few cases, coke.

At quite a number of works in the fireclay and salt-glazed pipe sections of the industry, some coal is obtained along with the clay in the mine or quarry. This coal is generally of low quality, is often of small size and of high ash content and sometimes has a high sulphur content, but is utilised perhaps in conjunction with other fuel for firing the boilers and drying sheds. They are mainly worked and utilised in certain districts, for example in the Burton-on-Trent and the Stourbridge areas. Analyses of such coals from the Stourbridge area show moisture contents of 8–12 per cent. and ash contents of 16–28 per cent. The highly refractory nature of the ash of the coal from this district permits of the larger coal being used on the intermittent kilns, the smaller sizes being used on the boilers and drying sheds.

Naturally the quality of the coal has a large influence on the fuel consumption on the kilns, the dryers and the boilers. Consequently where poor quality fuels are used the total fuel consumption per ton of product for the works is high, maybe several cwt. above the more normal figure.

FUEL CONSUMPTION PER UNIT OF PRODUCT

For many industries " yard sticks " can be established that offer a rapid method of assessing comparative thermal efficiencies of different works, but so diverse are the products manufactured, the raw materials processed, the methods of manufacture and types of plant used in the heavy clay and refractories industries that such figures as cwt. of coal per 1,000 bricks or per ton of fired ware may be most misleading. Even the thermal reactions occurring during the firing of clay products, for instance the endothermic reaction due to the decomposition of the clay molecule $Al_2O_3 . 2SiO_2 . 2H_2O$ and the exothermic reaction due to the burning out of carbonaceous matter, vary widely with the clay being used, i.e. the percentage of true clay substance and carbonaceous matter present in the clay, as well as with the percentage of inert material, such as grog, added. These reactions influence the heat requirements for firing.

Fuel consumption figures for individual works must, therefore, be considered in relation to these various factors. Taking the simple case of the firing of common building bricks in one type of kiln only—the continuous kiln—the fuel consumption varies at different works from a fraction of a cwt. to 8 cwt. per 1,000 bricks. This difference is mainly due to the nature of the clay and the amount of carbonaceous matter which it contains. Colliery shales, colliery blaes, Oxford clay, etc., from which a very large number of common bricks are made contain carbonaceous matter in varying amounts which assists in firing the bricks so that the actual coal consumed or fed to the kiln only amounts to 0·5 to 3·0 cwt. per 1,000 bricks approximately. Further, with these materials the bricks are generally made with electrically-driven plant by the stiff-plastic or semi-dry-pressed processes of manufacture and placed direct in the kiln without drying. The total fuel consumption for manufacture is therefore low at 10–25 units of electricity on the plant and 0·2–2·0 cwt. of coal on the kiln per ton of fired product. On the other hand, the fully plastic or wirecut process of manufacture is necessary when using many other clays throughout the country from which common bricks are made. Such clays usually contain little or no carbonaceous matter so that the fuel consumption on the kilns, maybe 5 cwt. per 1,000 bricks or more, is higher and since drying of the bricks is necessary before placing in the kiln, the total fuel for manufacture is generally higher, particularly where boilers are employed for power and drying purposes.

However, a broad classification has been made by dividing the industry into its various branches and determining the average fuel consumption per ton of fired product for each branch. The average figures so obtained are given in Table I.

TABLE I

AVERAGE FUEL CONSUMPTION PER TON OF FIRED PRODUCT DURING THREE YEARS OF THE WAR PERIOD

Group	No. of works	Coal consumption cwt. per ton product				Power consumption per ton of product					Total coal plus total equivalent coal of power used, cwt.
		Kilns			Total (kilns, dryers and boilers)	Electricity		Liquid fuel		Total equivalent coal, cwt.	
		Intermittent	Continuous	Total		Units	Equivalent coal, cwt.	Galls.	Equivalent coal, cwt.		
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1) Silica and basic refractories.	26	9·55	4·73	8·80	11·90	23·3	0·29	0·07	0·04	0·38	12·28
(2) Fireclay goods .	58	10·53	3·97	6·82	9·65	17·4	0·22	0·04	0·02	0·24	9·89
(3) Salt-glazed pipes .	36	13·81	—	13·81	17·82	7·5	0·09	0·08	0·04	0·13	17·95
(4) Composite works .	26	9·84	1·94	5·87	8·72	11·5	0·14	0·06	0·03	0·19	8·91
(5) Agricultural pipes, hollow building blocks, etc.	9	6·01	3·10	5·29	7·89	12·3	0·15	0·04	0·02	0·18	8·07
(6) Roofing tiles, floor quarries, etc.	9	7·33	—	7·33	10·05	15·2	0·19	0·27	0·14	0·33	10·38
(7) Common building bricks.	128	3·24	1·48	1·53	2·12	10·9	0·14	0·09	0·04	0·20	2·32

Individual works figures can differ largely from the average figures given in Table I, often because of difference in quality or type of product. The lower grades of firebrick made at some works only require to be fired to temperatures in the region of 1100° C., in contrast to 1400°–1470° C. for high quality refractory bricks at other works. Large fireclay blocks for glass tank furnaces and blast furnaces, weighing perhaps several cwt., must be fired very carefully and slowly throughout the firing : firing therefore takes 3–4 weeks as compared with 1–2 weeks for bricks, and the fuel consumption is therefore much higher. With silica refractories the temperature of firing and time of soaking at maximum temperature has a large influence on the degree of conversion of quartz to cristobalite and tridymite and hence on the properties and quality of the resulting product. Fuel consumptions for firing therefore differ appreciably, according to the specific gravity of the product, and are often much higher where high-grade products or special shapes and blocks are made. With silica and basic products fired to high temperatures of 1400°–1470° C., the quality of the coal has a decided effect on the fuel consumption. Thus, it is found that the range of fuel consumption for firing shows wide variations within the various groups.

THEORETICAL HEAT REQUIREMENT

Table II[1] gives a general idea of the actual heat required to raise the temperature of fireclay, fired clayware (and grog) and silica to temperatures of 1200° to 1450° C.

TABLE II

APPROXIMATE HEAT REQUIRED TO RAISE THE TEMPERATURE OF ONE TON OF DRY FIRECLAY, FIRED CLAY, OR SILICA TO 1200°-1450° C.

Material	Temperature ° C.	Theoretical heat required for material alone		
		B.Th.U.	Coal equivalent, cwt.	Assumed calorific value, B.Th.U./lb.
Fireclay . . .	1200	2,040,000	1·517	12,000
Fireclay . . .	1300	2,280,000	1·568	13,000
Fired clay (and grog)* .	1200	1,258,000	0·937	12,000
Fired clay (and grog)* .	1300	1,400,000	0·965	13,000
Silica brick . . .	1450	1,607,000	1·027	14,000

* Been fired previously.

Comparisons between these theoretical heat requirements and the consumption of fuel on the kilns in actual practice (see Table I), show that the continuous kilns, particularly those used for firing common building bricks, are thermally efficient, whilst intermittent kilns are less so. Taking the case of ordinary firebricks, fired to a temperature of 1200° C., the theoretical heat requirement is about 1·5 cwt. of equivalent coal per ton of material fired as compared with 2·5 to 3·5 cwt. of coal per ton of fired material on continuous kilns or 6–9 cwt. per ton on intermittent kilns.

HEAT LOSSES

For intermittent kilns, the main thermal losses are :—

(*a*) Heat lost in waste gases : (1) in dry combustion products ;
(2) in excess air ;
(3) in moisture derived from air, fuel and goods ;
(4) in unburnt gases.

(*b*) Sensible heat left in goods at end of firing, i.e. at maximum temperature.

(*c*) Heat stored in kiln structure at end of firing, i.e. at maximum temperature.

(*d*) Radiation, convection and conduction loss.

(*e*) Unburnt fuel in ashes.

The loss due to unburnt fuel is small compared with that of the other items.

With continuous kilns the main sources of loss are very similar to those of intermittent kilns except that the heat storage losses, item (*c*), are not taken into account and that the loss from item (*b*) is much less. With the continuous system of operation the heat in the fired goods is largely recovered in the cooling zone of the kiln.

Standard methods[2] of determining these heat losses and deriving thermal balances are given in the " Test Code for Kilns for Heavy Clayware, Including Refractory Materials ", No. 1081 published by the British Standards Institution in November, 1942. A number of these tests, on different types of kilns, has been carried out by the British Refractories Research Association during the past 15 to 20 years, the results of some of which are given later. In thermal statements the various heat losses are expressed as percentages of the total heat supplied to the kiln being tested. In consequence the figures obtained for different types of kilns are not comparable. For instance, the loss by radiation, convection and conduction may be 50–60 per cent. of the total heat supplied on a car tunnel kiln but only 30 per cent. on an intermittent kiln : yet the tunnel kiln is the more efficient unit with a much lower fuel consumption than the intermittent kiln. Strict comparison can only be made between different kilns for the firing of a given type of ware on the basis of the actual heat losses in B.Th.U. per unit of ware fired.

INTERMITTENT KILNS

1. THERMAL STATEMENTS

Two heat balances and other relevant data are given below to illustrate the fuel consumption and the magnitude of the various heat losses on intermittent kilns.

(*a*) *Intermittent Kilns, firing Salt-glazed Pipes.*—The following may be taken as a guide to the heat disposition for the firing of salt-glazed pipes in a down-draught kiln, using a normal type of clay firing to a temperature of about

1200° C. with a fuel consumption of approximately 12 to 14 cwt. of coal per ton of fired product.

Heat supplied	Per cent.	Heat accounted for and lost	Per cent.
(1) By coal used . .	97·0	(1) Unburnt fuel in ashes . .	3·0
(2) By combustibles in goods	3·0	(2) Heat in fired material at finishing temperature.	10·0
		(3) Heat used to complete irreversible reactions in goods.	1·0
		(4) *Heat in water vapour in flue gases from* :—	
		(*a*) Moisture in coal . .	0·5
		(*b*) Hydrogen in coal . .	5·0
		(*c*) Mechanical water in goods	1·0
		(*d*) Combined water in goods	1·5
		(5) *Heat lost in dry flue gases* :—	
		(*a*) Theoretical dry flue gases .	20·0
		(*b*) Excess air . . .	15·0
		(6) Heat stored in kiln structure at the finishing temperature and losses by radiation, convection and conduction (by difference).	43·0
	100·0		100·0

(*b*) *Intermittent Kiln, firing Silica Goods.*—The following figures were derived for the firing of silica goods to an average finishing temperature of 1400° C. in a round down-draught kiln, coal fired by hand to fireholes with horizontal grates.

Heat supplied	Per cent.	Heat accounted for and lost	Per cent.
(1) By coal used . .	100·0	(1) Unburnt fuel in ashes . .	6·0
		(2) Heat in fired materials at finish of firing.	13·5
		(3) *Heat in water vapour in flue gases from*—	
		(*a*) Coal used . . .	5·5
		(4) *Heat in flue gases*—	
		(*a*) Sensible heat in dry gases .	38·0
		(*b*) Combustibles in gases .	1·0
		(5) Heat stored in kiln structure and losses by radiation, convection and conduction, etc. (by difference).	36·0
	100·0		100·0

2. DISCUSSION OF THE VARIOUS HEAT LOSSES

(*a*) *Flue Gas Loss.*—In the firing of intermittent kilns combustion conditions, instead of being controlled to give efficient combustion of the fuel, must be adjusted to suit the requirements of the goods being fired. The firing of a kiln of clayware can be divided into three periods, namely, the drying or water-smoking period, the early firing or preheating and oxidation period (200°–850° C.), and the full firing or finishing period. Combustion conditions vary for each of these periods.

The goods as set in the kiln may contain from about 3–4 per cent. up to 13 per cent. of water, which must be removed by very slow heating at low and very gradually increasing temperatures. Suitable drying conditions for wet goods are obtained when the CO_2 content of the waste gases is 1–2 per cent., so that 1,000–1,500 per cent. of excess air over and above combustion requirements are passed through the kiln during the early stages of the water-smoking period. The necessary excess air is gradually decreased as the temperature increases up to 100°–120° C., when the percentage of excess air is about 200. From this stage up to 850° C., that is during the preheating and oxidation period, excess air is required to assist in removing the combined water from the goods over the temperature range of 450°–600° C. or so, and to burn out any carbonaceous matter in the goods. The excess air required is usually such as to give about 10 per cent. of CO_2 in the waste gases, although for highly carbonaceous goods it may be necessary to lower this to about 8 per cent. If more excess air than this is used the heat losses may be much greater than necessary.

Excess air control is of most importance during the finishing stage of the firing, when the temperature of the waste gases is high. For firing under oxidising conditions, it is often necessary to have sufficient excess air present to give about 12 per cent. CO_2 in the waste gases up to 1000° C. As the firing temperature increases above this, excess air should be reduced with corresponding increase of CO_2 content until the proportion of the latter increases to 16–18 per cent. The smaller excess is permissible at high temperatures because of the relative ease with which complete combustion can be obtained.

The extent of the heat losses obtaining at high temperatures in the waste gases and through excess air is illustrated in Table III.[1] For instance, when the waste-gas temperature is 1000° C., with 50 per cent. excess air present (12 per cent. CO_2) almost 60 per cent. of the total heat being supplied to the kiln is carried away in the waste gases ; with 100 per cent. excess air 77 per cent. of the heat supplied ; and with 150 per cent. excess air (7 per cent. CO_2), 94 per cent. of the heat supplied.

TABLE III

HEAT LOST IN WASTE GASES AT DIFFERENT TEMPERATURES AND WITH DIFFERENT PROPORTIONS OF EXCESS AIR (EXPRESSED AS A PERCENTAGE OF THE HEAT AVAILABLE FROM COAL WITH A GROSS CALORIFIC VALUE OF 14,000 B.TH.U. PER LB.).

Waste-gas temperature	Percentage heat loss			
500° C.	22	30	38	46
1000° C.	43	60	77	94
1200° C.	52	73	95	—
1400° C.	63	88	—	—
CO_2, per cent.	18·5	12·2	9·1	7·2
Excess air, per cent. . . .	0	50	100	150

Since theoretical combustion conditions cannot be utilised throughout the firing of a kiln, there must always be a loss due to excess air. Endeavours should be made to keep this to the minimum required by regulated control of the primary and secondary air supplies and of the draught. In practice the amount of excess air used at temperatures above 850° C. is often higher than it should be, more particularly towards the end of each firing interval when the CO_2 may be below 9 per cent. or even 7 per cent. More regular and frequent firings and controlled admittance of secondary air through flues reduce the CO_2 fluctuations between firings and result in a higher average CO_2 figure.

It should be stated that certain goods, such as blue bricks, roofing tiles and quarries, require to be fired under reducing condition above 1000° C. if satisfactory blue coloured products are to be obtained. Consequently the loss due to unburned gases in the waste combustion products must, in these cases, be high.

With intermittent kilns the flue gases pass away to the stack at gradually increasing temperatures as firing progresses, and at the finishing stage may leave at temperatures of 1000° to 1400° C. according to the nature of the goods being fired. If the layout were suitable some recovery of this heat, which amounts to 30–40 per cent. of the total heat supplied to the kiln, could be effected by inter-connection of kilns. Generally, however, the kilns are spread about the works in such a manner that complicated flue systems would be necessary to recover the heat from the waste gases for any purpose. The large heat losses from such flues, their comparatively high cost and the fact that the kilns may only be on fire above 200° C. for 2 to 5 or 6 days per fortnight or even per month weigh against waste-gas utilisation.

(*b*) *Sensible Heat in the Fired Goods.*—At the finish of firing, when the maximum temperature required has been obtained, the kiln is allowed to stand and cool down. For many types of ware this cooling is as important as the firing and must be carried out carefully to avoid cracking or dunting of the ware or in certain cases change in colour of the goods. Consequently both the heat in the fired ware and that in the kiln structure is usually wasted. However, in some cases use is made of this heat by extracting hot air by fan from the kiln during the cooling period, which is passed through metal ducting to dryers, preferably of the chamber or car tunnel type where it can be more efficiently used than in open shed dryers.

(*c*) *Loss by Radiation, Convection and Conduction, and Kiln Storage Loss.*—The loss of heat from these sources is high, generally of the order of 30–40 per cent. of the total heat supplied to the kiln. Saving can be effected by the application of insulation but consideration must be given to the position of its application and its effect on the firing and on the refractories being used. With down-draught kilns, the heat in the bottom of the kiln usually lags behind that of the top. Thus to bring up the bottom heat quicker and get greater temperature uniformity it would seem advisable to provide a 6 to 9 in. thick course of insulating concrete in the base when new kilns are erected. With existing kilns fuel savings may be obtained by covering the 9 in. thick crown with a 3 to 4½ in. course of insulating bricks followed by a 2-in. course of pavers or common bricks. This may result in lengthening the time of cooling and a tendency to increase the heat in the top rather more quickly than usual. When insulation is applied, the temperature throughout the 9 in. thickness of material forming the original crown is appreciably increased as compared with when it was not insulated. The material must be sufficiently refractory to stand up to the new conditions.

For the firing of goods to temperatures of the order of 1150° C. or possibly 1200° C., the use of refractory insulation applied to the internal or hot face of the kiln should be considered. High-grade refractory insulation material can be obtained for using on the hot face, i.e. in the crown, side walls, top of side walls, etc., up to these temperatures, and has been applied to intermittent kilns for firing facing bricks, commons and multi-coloured bricks, red quarries, terra cotta, red roofing tiles, fireclay goods, etc. Its use is not recommended for salt-glazed kilns or for kilns firing under heavy reducing conditions. The successful use of refractory insulation often depends to quite a large extent on the constructional details.

(*d*) *Unburnt Fuel in Ashes.*—This loss is generally quite small but may increase if the percentage of fines in the coal is excessive. Such fines tend to fall through the bars, particularly during the early stages of firing, but the loss in this case may be reduced by re-feeding to the fires.

CONTINUOUS KILNS

The design of continuous kilns is such that heat is recovered from the fired goods which are cooling, and use is made of the heat generated in the combustion zone from the fuel burnt not only to fire the goods to the maximum temperature but also to preheat the goods in front of the firing zone. The waste gases are exhausted to the stack or fan at low temperatures of the order of 80°–150° C. throughout the firing so that a large proportion of their heat is abstracted before they leave the kiln system. Continuous kilns are therefore by design efficient. This is particularly the case for top-fired kilns of the Hoffmann and related types where the fuel is burnt within the kiln amongst the goods. The fuel consumption on continuous kilns is roughly one-third to a half that of intermittent kilns firing the same type of product (see Table I).

As with intermittent kilns the fuel consumption per unit of product depends on the type of ware being fired, the quality of the product, the temperature of firing, the quality of the coal, etc. This has been indicated in previous remarks and is further demonstrated by the figures in Table I and the following thermal balances of various types of continuous kilns.

I. THERMAL STATEMENTS

(*a*) *Manchester-Hoffmann Kiln.*—W. Emery[3] studied this 16-chamber top-fired barrel arched type kiln (no division walls between chambers) firing common building bricks, made from a clay containing carbonaceous matter (2·48 per cent. carbon on the dry brick basis), to an average temperature of 1000° C. The following approximate results were obtained. During the test four chambers containing 42,580 bricks of fired weight 151·6 tons were fired with 4 tons 11 cwt. of coal of calorific value 10,530 B.Th.U. per lb.

Summary of Heat Balance Data

	Percentage of total heat
(1) Unburnt fuel in ashes	2·14
(2) *Heat in water vapour in flue gases derived from—*	
(*a*) Hydrogen in fuel	1·52
(*b*) Hydrogen present in clay	2·82
(*c*) Mechanical and hygroscopic moisture in clay	28·23
(*d*) Chemically combined water in clay	16·51
(3) Sensible heat in dry flue gases	26·15
(4) Sensible heat left in fired goods after cooling in kiln	4·34
(5) Radiation, convection, conduction (by difference)	18·29
	100·00

Summary.—2 cwt. 15 lb. of fuel are required to fire 1,000 common building bricks made from the given carbonaceous clay. The bricks are fired with 3 per cent. of their weight of fuel.

Average stack gas analysis : CO_2 = 1·6 per cent.
,, ,, ,, temperature : = 85° C.

Note.—The low CO_2 content of the waste gases is partly due to the use of a hot air system on the kiln whereby the fired bricks in the cooling zone are cooled and the hot air so produced is admitted to chambers of freshly set green bricks in order to dry them. Further heat is thus recuperated within the kiln but the hot air so utilised dilutes the waste gases and lowers the CO_2 content.

(*b*) *Belgian Kiln.*—S. R. Hind[4] studied this barrel arched type kiln, with 28 chambers each having a capacity of about 6,000 bricks, side-fired with coal at the wicket on to a grate extending across the width of the chamber. The kiln was utilised for firing fireclay goods to an average temperature of 1200° to 1230° C. and average Seger cone 11 to 13. During the test five chambers containing a fired weight of 106·3 tons were fired in 80 hours with 9 tons 17 cwt. of coal of gross calorific value of 9,320 B.Th.U. per lb.

Heat Balance

Heat supplied	Per cent.	Heat accounted for and lost	Per cent.
(1) By fuel burnt	91	(1) Unburnt fuel in ashes	1
(2) By combustibles in goods	8	(2) Sensible heat left in fired goods after cooling in kiln.	9
(3) By sensible heat in goods	1	(3) Sensible heat in dry flue gases	33
		(4) Heat in water vapour in flue gases.	35
		(5) Loss by radiation, conduction, convection, etc. (by difference).	22
	100		100

Summary :

Fuel consumption per ton of fired goods	1·83 cwt. (9·15 per cent.)
Fuel consumption per 1,000 of 9×4½×3 in. bricks	6·96 cwt.
Average stack gas analysis CO_2	1·97 per cent.
Average stack gas temperature	117° C.

(*c*) *Woodall-Duckham Kiln.*—S. R. Hind[5] was responsible for the work on this kiln which is a 16-chamber arched tunnel with chamber separating walls, making essentially 16 inter-connected down-draught kilns, each heated by four fireholes situated at the four corners of the chambers. The gases from the fires pass up a bag wall into the chamber on fire, down through the goods, through a chequered floor and thence by flues to the bag wall space in the next chamber, through the goods in this chamber and so on as is usual for continuous kilns.

The kiln was utilised for firing fireclay goods to a maximum temperature of 1360° C. During the test, two chambers containing a fired weight of 128·7 tons were fired in 98 hours on 20 tons of fuel having a C.V. of 11,890 B.Th.U. per lb. The dry goods prior to firing contained 1·2 per cent. of carbon.

Heat Balance

Heat supplied	Per cent.	Heat accounted for and lost	Per cent.
(1) By fuel burnt	90	(1) Unburnt fuel in ashes	4
(2) By combustibles in goods	10	(2) Sensible heat left in fired goods after cooling in kiln.	9
		(3) Sensible heat in dry flue gases	13
		(4) Heat in water vapour in flue gases.	14
		(5) Loss by radiation, conduction, etc. (by difference).	60
	100		100

Summary :

Fuel consumption per ton of fired goods	3·11 cwt. (15·5 per cent.)
Fuel consumption per 1,000 firebricks	11·26 cwt.
Average waste-gas analysis at fan CO_2	1·64 per cent.
Average waste-gas temperature at fan	46·4° C.

(*d*) *Carder Tunnel Kiln.*—This car tunnel continuous kiln, in which the goods travel through the kiln on cars, is 214 ft. long and producer-gas fired. Stoneware jars and bottles (once-fired ware) are fired to a maximum temperature of 1220° C. They are placed in fireclay containers (saggars). The weight of the goods is only 15·8 per cent. of that of the total material placed and fired on the cars.

During the test, conducted by S. R. Hind[6], 7 tons 10 cwt. of nut coal of gross calorific value 11,950 B.Th.U. per lb. was consumed in firing 11·63 tons of goods along with 61·8 tons of setting material (of which 4·06 tons was green unfired material).

Heat Balance of Gas Producer :

Ashes—unburnt fuel	0·5 per cent.
Gas—latent heat	80·3 „ „
sensible heat	8·9 „ „
heat in water vapour carried	2·8 „ „
Radiation, convection and conduction	7·5 „ „
	100·0

Heat Balance of Kiln apart from Gas Producer

Heat supplied	Per cent.	Heat accounted for and lost	Per cent.
Gas :		*Heat lost in fired truck leaving kiln :*	
(1) Latent heat . . .	84·0	(1) Heat in goods drawn .	1·6
(2) Sensible heat . .	9·3	(2) Heat in trucks drawn .	6·3
(3) Heat in water vapour carried.	2·9	(3) Heat in saggars and supports	8·6
Carbon in goods :		*Heat in water vapour in flue gases from :*	
(1) Pots and green saggars .	2·8	(1) Mechanical water in goods and green saggars.	0·4
Trucks and goods :		(2) Combined water in goods and green saggars.	1·9
(1) Sensible heat brought in	1·0	(3) Moisture in air drawn through kiln.	0·2
		(4) Water from hydrogen of gas	4·8
		(5) Water carried as vapour by gas.	2·3
		Lost in dry flue gases :	
		(1) Unburnt gas . . .	0·0
		(2) Sensible heat . . .	18·4
		Lost by radiation, etc. (by difference).	55·5
	100·0		100·0

Summarised Heat Balance of the Kiln as a Whole

Heat supplied	Per cent.	Heat accounted for and lost	Per cent.
(1) Fuel	94·9	(1) Unburnt fuel in ashes . .	0·5
(2) Steam blast . . .	1·6	(2) Sensible heat in ware, saggars and trucks leaving kiln.	15·2
(3) Carbon in ware and green saggars.	2·6	(3) Heat in water vapour in flue gases.	8·9
(4) Sensible heat in trucks and goods entering kiln.	0·9	(4) Sensible heat in dry flue gases .	17·0
		(5) Radiation, convection and conduction :	
		(*a*) Gas producer . .	7·2
		(*b*) Kiln . . .	51·2*
	100·0		100·0
		**Distribution of loss :*	
		(1) Preheating zone . .	15·0
		(2) High fire zone . . .	36·0
		(3) Cooling zone	49·0

Of the heat lost by radiation, convection, etc., from the kiln, about 14 per cent. is reclaimed for drying purposes (hot air drawn from the kiln), representing about 7 per cent. on the heat balance, and a further indefinite amount effects shop warming.

Summary :

Fuel consumption per ton of fired goods . 9·59 cwt.

Goods are fired with 48 per cent. of their weight in fuel which represents a saving of 71 per cent. on intermittent round oven practice.

Average stack gas analysis CO_2 . . 4·7 per cent.

Average stack gas temperature . . 162° C.

2. DISCUSSION OF THE VARIOUS HEAT LOSSES (CONTINUOUS KILNS)

The main sources of loss have been previously stated. The minor losses are : (*a*) those in the unburnt fuel, approximately 1 to 4 per cent., and (*b*) the sensible heat in the goods and trucks leaving the exit end of the car tunnel kiln (up to 15 per cent.) or of the goods being drawn from the chamber or barrel arched types of kiln (4 to 10 per cent.) after they have been cooled from maximum firing temperature within the kiln. A high loss under (*b*) indicates that the kiln is too short, that the kiln is being worked at too fast a rate or that insufficient chambers of cooling goods are being maintained behind the firing zone.

The main losses are, however, those in the flue gases and those by radiation, conduction and convection from the kiln. For the firing of common building bricks in Hoffmann, Belgian and chamber types of kilns, the latter loss is of the order of 20 per cent. These kilns generally are not insulated but rely on the thickness of the wall and roof structures. For car tunnel kilns the radiation, conduction and convection losses, together with unaccounted losses (by difference) are of the order of 30 to 60 per cent. In many cases, these high losses obtain, e.g. for fine ceramic products, even although the kiln is well insulated. For car tunnel kilns the heat in the hot air withdrawn from the kiln and used extraneously in dryers, etc., amounts to 5 to 20 per cent. of the total heat supplied to the kiln.

In the case of continuous kilns of the Hoffmann, Belgian and chamber types firing common building bricks, the heat in the waste gases passing to the stack amounts to about two-thirds or roughly 40 to 80 per cent. of the total fuel used for firing (including the carbonaceous content of the clay). This heat is contained in the dry combustion gases, in excess air and in the steam derived from the fuel and the clayware. The loss due to the latent heat in the water vapour from the various sources must be considered as unavoidable—the magnitude of the loss will depend on the moisture and hydrogen content of the fuel and on the percentages of mechanical and combined water in the bricks or clayware being fired in the kiln. Semi-dry pressed bricks may contain 17 to 18 per cent. of mechanical water as placed in the kiln, stiff-plastic bricks 12 to 14 per cent., and wirecut bricks which are dried prior to setting, up to 10 to 11 per cent. approximately. The combined-water content of the bricks may be up to about 10 per cent. but is often lower than this. Hence when firing on these kilns, the forward zone is used for drying the bricks, hot air being drawn from chambers of cooling bricks behind the fire and passed into chambers of green bricks in the water-smoking or hot-air drying zone in front of the fires, whilst the combustion gases travelling directly forward from the fires, and preheating chambers also assist the drying. In the manufacture of common bricks it is often considered to be more economical in fuel to dry in the kiln in this manner than to dry the bricks externally in separate dryers prior to placing the bricks in the kiln. The loss due to latent heat in the water vapour in the flue gases is therefore variable according to the characteristics of the goods set in the kiln, and may amount to 15 to 40 per cent. of the total heat supplied. Of the heat in the theoretical combustion products and excess air in the waste gases a certain proportion must be considered as necessary for the operation of the kiln. For satisfactory operation of the kiln, waste-gas temperatures of about 100° C. appear to be necessary with chimney draught together with about 500 per cent. excess air. The latter assists in drying and is partly derived from the hot-air system as well as from inleakage which cannot be avoided on these types of kiln.

Continuous kilns are very efficient units compared with intermittent kilns, recuperation of heat taking place both in the cooling zone and in the preheating zone. The combustion gases from the firing zone serve to preheat the unfired goods and assist in drying them before being exhausted to the stack or fan at a comparatively low temperature. Because of this the heat losses in the waste gases are often overlooked. It can be shown, however, that these losses can be very significant. The losses in the waste gases derived from the combustion of the fuel, including the water in the coal, and from excess air, are given in Table IV. With no excess air, the heat loss at waste-gas temperatures of 100°, 150° and 200° C. are roughly 7, 9 and 11 per cent. of the total heat of the fuel respectively. The losses, however, increase very rapidly with increase of excess air. With 500 per cent. excess air and the same temperatures, they are 21, 31 and 41 per cent. respectively.

TABLE IV

HEAT LOST IN THE WASTE GASES OF COMBUSTION AT DIFFERENT TEMPERATURES AND WITH DIFFERENT PROPORTIONS OF EXCESS AIR (EXPRESSED AS A PERCENTAGE OF THE HEAT AVAILABLE FROM COAL WITH A CALORIFIC VALUE OF 14,000 B.TH.U. PER LB.)

CO_2 content of flue gases, per cent.	Excess air, per cent.	Percentage heat loss*					
		Temperature of waste gases, °C.					
		50	100	150	200	250	300
18·5	0	4·8	6·7	8·6	10·5	12·5	14·5
12·3	50	5·4	8·1	10·9	13·6	16·4	19·2
9·2	100	6·0	9·5	13·1	16·7	20·3	24·0
7·3	150	6·6	10·9	15·3	19·8	24·2	28·8
6·1	200	7·1	12·3	17·5	22·8	28·0	33·6
4·6	300	8·3	15·2	22·1	29·0	35·9	43·2
3·6	400	9·4	18·0	26·5	35·2	43·7	52·7
3·0	500	10·6	20·8	31·0	41·2	51·5	62·3
2·6	600	11·7	23·6	35·5	47·3	59·3	72·0
2·3	700	12·8	26·4	40·7	53·6	67·2	81·5
2·0	800	14·0	29·2	45·2	59·7	75·0	91·0
1·6	1,000	16·3	34·9	54·0	72·0	90·5	—

* Includes moisture in coal.

The total loss in the waste gases, i.e. in the products of combustion of the fuel and excess air, often exceeds that which would be obtained under the assumed satisfactory conditions of operation for the firing of building bricks in Hoffmann and related types of kiln, i.e. 500 per cent. excess air and waste-gas temperature of 100° C. (loss 21 per cent.). In practice waste-gas temperatures vary on different kilns from 50° to 250° C. and excess air from 500 to 800 or 900 per cent. With a CO_2 content of 2·3 per cent., i.e. 700 per cent. excess air (which may be assumed as being about average) and a waste-gas temperature of 130° C. the loss is about 35 per cent. instead of 21 per cent. With the higher waste-gas temperatures and greater excess of air, which are sometimes met, the loss is still higher. If there were 800 per cent. excess air present and the waste-gas temperature slightly exceeded 300° C., practically the whole of the heat supplied to the kiln would pass away in the waste gases.

SUGGESTIONS FOR FUEL SAVINGS

1. BOILERS

On those works where boilers are used for power purposes, generally those where heavy clay goods are made by the plastic or wirecut methods, the type and efficiency of the steam plant employed differ considerably. In practically every case the exhaust steam is used for drying the clay goods, mostly by passage beneath drying floors. Because of this double use of the steam the efficiency of steam generation and utilisation on the older or smaller works is often overlooked, particularly where the demand of steam for drying exceeds that supplied by the engine. Sometimes the cut-off on the steam engine is regulated to suit drying requirements. On up-to-date works, the boilers, generally of the Lancashire type, are provided with economisers or feedwater preheaters, probably with superheaters, and maybe are fitted with mechanical stokers, and the generated steam is utilised in the adjacent engine house to drive horizontal or vertical compound engines. The steam engines either provide direct drive to the plant machinery, or drive a generator, in which case the separate plant units are driven by their own individual electric motors. The exhaust steam is then conveyed from the one engine house to the drying sheds or dryers.

On some of the older and smaller works, the steam plant often consists of one or more hand-fed Lancashire boilers without economisers, etc., supplying saturated steam to various single-cylinder steam engines distributed throughout the works, some quite small, for instance those employed for haulage purposes. In such cases the exhaust steam from the larger engines is passed beneath dryer floors, but for the smaller engines, which may be used only intermittently, heat is lost in the exhaust steam. Standby losses—which are often very significant—may be further increased by leaking valves or flanges. Loss by condensation and the effect on the efficiency of the engines by using such wet steam may be considerable. The efficiency of utilisation under such conditions is low. Fortunately, for the main part the exhaust steam is utilised for carrying out the necessary drying of the clay goods, so that the efficiency is somewhat improved. Most clay works only operate on day shift 48 to 50 hours per week, the boiler being banked up at night and at weekends, except when some live steam has to be supplied to the drying sheds at night, etc., in winter.

At the present time many improvements could be effected on the boilers, steam mains, and the engines, by further insulation, by attending to steam leaks, by making use of exhaust steam from the smaller engines and feed pumps which is often wasted at present, by attending to air inleakage at the boiler, by flueing out and scaling more regularly, by feedwater treatment, etc. Such points have been adequately covered in the fuel efficiency bulletins. The efficiency of these plants could be considerably improved by paying attention to the various points given in these bulletins or by bringing the plant up to date. At works where the plastic or wirecut process is employed in manufacture, it must be remembered that if steam were replaced by purchased electricity for power purposes, some method of heating has still to be employed for drying. If this is steam then generally it is preferable to generate high-pressure steam and use the steam engine as a reducing valve to supply low-pressure steam for drying.

Chamber and car tunnel types of dryer are more efficient than hot floor drying sheds, and also can make more efficient use of waste heat derived from kilns (hot air extracted from cooling sections of continuous kilns or during the cooling of intermittent kilns). Hot floors are generally considered essential for the drying of large blocks, special shapes, etc., but for normal sized bricks, etc., the greater use of chamber or car tunnel dryers would reduce the heat required for drying and so decrease the demand for exhaust steam for this purpose. This would reduce the need for running engines inefficiently or using inefficient engines.

2. KILNS

A. General

(1) *Increased Use of Continuous Kilns*[7].—The fuel consumption of continuous kilns per unit of product is approximately a half to a quarter that of intermittent kilns. The most effective way of saving fuel, therefore, is to replace the intermittent process of firing as far as possible by a continuous process. As stated previously, intermittent kilns are regarded as being more or less essential for the firing of certain types of products. The savings of fuel to be obtained by such replacements far exceed any savings to be effected by modification of existing intermittent kilns.

B. Intermittent Kilns[7]

(1) *Condition of Kiln.*—The condition of the kiln in general has quite a large effect on fuel consumption. When erected the kiln should be substantially built with good and well-drained foundations. Wet flues and base considerably retard the firing of a kiln : the indrawing of air through faulty brickwork and flues increases the heat losses or may reduce the draught. The interior of fireholes and bag walls should be frequently inspected : enlarged fireholes and faulty firebars give rise to faulty combustion conditions and increased loss of fuel in the ashes. Floor flues should be inspected regularly and cleaned when necessary. Choking of these flues or the sub-floor flues with sand used for setting, clay used for packing up, débris from the goods or setting materials, occurs particularly on kilns with open type floors, and they should be cleaned before the draught on the kiln is affected.

(2) *Wickets.*—Although kiln walls are 2 to 3 ft. or more thick, wicket walls are often only made 9 in. thick, and, in a few cases, they have been observed to be only 4½ in. thick. They should be at least 14 in. thick, well clayed over on the outside, and should be washed over periodically with clay wash during the firing to reduce air inleakage. Preferably two wicket walls, each 9 in. thick, clayed over and separated by an air space of 3 to 4 in. should be used, or alternatively one constructed of 9 in. of refractory insulating brick and 4½ in. of common brick. This will reduce heat losses from this position on the kiln.

(3) *Insulation.*—Kiln crowns are often only 9 in. thick. These should at least be covered with a 2 to 3 in. course of paving brick. Some fuel saving may be effected on existing kilns by covering the 9 in. crown with 3 to 4½ in. of insulating brick followed by a 2 in. course of pavers.

With new kilns or when kilns are to be rebuilt, the provision of a 6 to 9 in. layer of insulating concrete in the base should assist in bringing up the temperature in the base of the kiln, which normally lags behind that of the top, and also lead to fuel saving.

For kilns firing to temperatures up to 1150° C. refractory insulation applied to the internal hot face can effect quite large savings by reducing heat storage losses and conduction through the walls and crown.

(4) *Size of Kiln.*—In general, the larger the kiln the lower the fuel consumption per unit of product. Small kilns should therefore be used as little as possible. Thus on some salt-glazed pipe works kilns with capacities of 10, 12 or 15 tons are used as against capacities of 30 to 45 tons. As an example of the saving to be obtained, kilns of 40,000 to 50,000 roofing tile capacity having a fuel consumption of about 9 cwt. per 1,000 tiles were replaced at one works by more modern kilns of 100,000 tile capacity, when the fuel consumption was reduced to 6 to 7 cwt. per 1,000 tiles. With very large round down-draught kilns such savings must be weighed against the possibility of shorter life of the crown because of its size and weight and the possibility of less uniformity of heating throughout the kiln. This last point is of great significance in the overall efficiency of firing.

(5) *Weight of Goods Fired in the Kiln.*—The greater the weight of ware fired in a kiln within certain limits the more economical is its operation in respect to fuel consumption per ton of product. Although the total fuel to fire the kiln may be increased slightly thereby, that *per ton* of product is lowered. Savings by this means, however, must be considered conjointly with the quality of the goods ; the ware should not be set so densely or the kiln so full as to interfere with the firing. As an example, with hollow ware such as salt-glazed pipes, the fuel consumption per ton of product has, on occasions, been reduced appreciably in consequence of the amount of odd stuff set on top of the pipes and by nesting small pipes within larger pipes.

(6) *Kiln Schedule.*—Savings in fuel, the extent of which are not often realised, can be effected by making use of the minimum number of kilns capable of dealing with the output. For a given product and kiln the time of firing, cooling, drawing of fired goods and setting of green goods are known and are roughly constant. The kiln should be kept constantly working on this minimum schedule between consecutive firings. In this way maximum advantage is obtained of the large amount of residual heat stored in kiln structure, foundations and flues.

(7) *Combustion Control.*—Excess air can best be controlled by providing fire-doors to the top firing holes and secondary air flues with metal slide control to each fire-hole.[9] The design of grate should be such that ash can be easily removed but that an undue amount of unburnt fine coal does not fall through the bars. Bars should be replaced if burnt out or worn, so as to keep the spacing between them constant. A damper which is readily adjusted and easily accessible should be provided in the main flue to each kiln ; this is particularly important where the stack is high or more than one kiln is connected to a stack.

(8) *Reduction of Time of Firing.*—Reduction of the time of firing, particularly if affected at the higher temperature stages, results in fuel savings. It must be ensured, however, that such reductions do not have a detrimental effect on the product. Times of firing vary according to the type and quality of the product, the temperature of firing, the characteristics of the kiln, the weight of the ware set in the kiln, the size of the individual articles, the characteristics of the ware as set (water content, carbonaceous content, etc.), the quality of the coal, etc. The following outlines various ways in which the time of firing may be reduced.

(*a*) By setting dry ware, or ware as dry as is permissible, in the kiln, thereby reducing the length of the water-smoking period and increasing the kiln turnover. Wet ware, besides lengthening the time required for water-smoking, may lead to the production of faulty ware if drying in the kiln is rushed or imperfectly carried out.

(*b*) Firing is greatly assisted when setting is regularly carried out, leaving sufficient free space for travel of the gases and making sure that floor flues are not unduly restricted by the ware placed above them.

(*c*) Improvements in kiln design, modification of firemouths or grates, modification of floor flues or sub-floor flues, etc., may result in reduced firing times and to fuel savings.

(*d*) The skill of the fireman and the amount of attention which he pays to his work can have a considerable effect on both the fuel consumption and the quality of the resulting product. Firing with coal, preferably at frequent intervals ; controlling of excess air, either by adjustment of the air space over the top of the fuel bed or by adjustment of the slides if secondary-air flues are installed ; cleaning the fires at the requisite times ; increasing the heat uniformly round the kiln and, during the finishing period, bringing up the bottom heat as close to that in the top of the kiln as possible without overfiring the top, etc. These points, together with the determination of when the firing of the kiln is to be finished, call for a large amount of skill on the part of the fireman. For instance, delay in finishing at top heat can increase the fuel consumption considerably, yet finishing too soon would result in light-fired ware, particularly from the bottom of the kiln.

(*e*) The frequency and methods of ashing out are particularly important, especially at the higher temperature stages of the firing. Cases are known where lack of attention to this point has prolonged the firing considerably. On the other hand, ashing out too frequently can cause excessive loss of heat in the red hot ashes and unburnt fuel withdrawn, and through cold air pulling through the fire-holes during the ashing out process. The times of ashing out or cleaning the fires depend on the character and content of ash in the coal, so no fixed schedule can be laid down. However, fires should be cleaned as soon as difficulty is met in maintaining the desired rate of combustion or temperature rise. In order to reduce the tendency for the kiln temperature to fall during the ashing operation, alternate fire-holes should be ashed out, the remaining fires being cleaned a few hours later. This also ensures better combustion of the rather heavy charges of coal required after ashing. One fire-hole only should be treated at a time, i.e. push back the incandescent fuel, remove the ashes, pull back the red hot cokes on to the bars and then re-charge with fresh coal—so working round from fire-hole to fire-hole. Two or more men can carry out the ashing operation more efficiently and effectively than one man.

(*f*) At some works kilns are kept on fire longer than necessary because the fireman cannot or is not allowed to finish the kiln on his own or at night. This may mean prolonging the firing for 6 to 12 hours at top temperature to the following morning when the chief burner, foreman or manager is available. In the case of blue goods, salt-glazed pipes, etc., this is often explained by the difficulty of judging trials of such materials drawn from the kiln, by night. All burners should be instructed how to finish kilns or arrangements made to finish them when they are ready.

(9) *Quality of Coal.*—The use of poor quality coals can lead to considerable increase of fuel consumption. On many clay works fuel consumption on kilns

and boilers has gradually increased over the past few years due to the consumption of lower grade fuels. It is realised that such fuels must be used and the clay industries are assisting the national effort by consuming quite large quantities of them. However, their use in quite a number of cases, as for instance for firing to high temperatures on intermittent or continuous kilns, on gas producers, on certain highly loaded mechanically-fired boiler installations, etc., is not advocated because of the excessive increase in consumption which would result together with the production of badly fired ware, or the non-attainment of the requisite temperature or output.

(10) *Mechanical Firing.*—The mechanical firing of intermittent kilns has been receiving increased attention during the past few years. A few works have the stokers installed or are installing them generally on one of their kilns. In practice fuel savings of from 10 to 30 per cent. or even more are claimed. Savings, of course, depend on the efficiency of previous practice, but in any case a saving of the order of 10 to 15 per cent. is to be expected from mechanical stokers because of the constant fuel feed and consequent reduction of heat losses in excess air and unburnt gases in the waste flue gases and the possibility of progressive increase of temperature in the kiln. The application of stoker firing to intermittent kilns in this country should be regarded as being in the experimental stage, although a few kilns are being successfully fired with them.

(11) *Utilisation of Heat in Fired Goods at Completion of Firing.*—With intermittent kilns the sensible heat in the goods and kiln at the completion of firing, when the goods are at their maximum temperature, is generally wasted. In certain cases hot air is drawn off from the kilns by means of a fan and metal ducting connected to a number of kilns during the cooling period and utilised in the drying sheds. This system has a number of points to commend it, but the difficulties should be frankly recognised. Kilns are usually widely distributed throughout the works and maybe are at some distance from the drying sheds—this means long lengths and therefore high cost for ducting and high loss of heat, particularly in winter : the kilns and therefore the main part of the ducting are out in the open exposed to the weather : to insulate ducting 18 to 24 in. and above in diameter is expensive : the ducting nearest the kilns tends to burn out and to corrode. Troubles may arise in regard to the application or distribution of the hot air within the drying sheds to effect uniform drying. However, a number of works have applied this system with success where the kiln layout was suitable.

(12) *Possibility of Inter-Connection of Kilns.*—For those products which have to be fired in intermittent kilns, the possibility should be considered of the interconnection of the kilns so as to make use of the heat in the waste combustion gases instead of exhausting direct to the stack. This would entail the construction of connecting flues with the necessary control dampers between kilns and the provision of a fan or high stack to cope with the higher draught requirements. The layout of existing kilns at many works is not favourable to such inter-connection.

(13) *Control Instruments.*—For fuel economy and to assist in the production of satisfactorily fired goods, pyrometers, preferably recording pyrometers, should be installed. Two pyrometers, one in the top and the other in the bottom of the kiln, are best. If one only is provided, in the top, then trials, seger cones, heat recorders, etc., should be used at the base. By installing recording pyrometers a check is kept on the firing schedule and on what is happening at night and at weekends. Alternatively, the fireman may be requested to fire according

to a definite temperature schedule pre-drawn on the chart. Reduction of firing time and the stages in the firing schedule where such reductions can be made may sometimes be deduced from a study of the charts.

Excessive draught gives rise to high fuel consumption and to high excess air losses. Thus a draught gauge connected to the main flue to each kiln should be of service, particularly on kilns working into high stacks or where several kilns are connected to one stack. Dampers to individual kilns could then be operated according to the draught required. In practice they are scarcely ever used on clayworks.

Either a portable CO_2 indicator, a CO_2 recorder or a gas analysis apparatus should be available at the works to determine the efficiency of combustion of the fuel and the percentage of excess air in the waste gases. This instrument can, of course, be used on the different kilns and on the boilers.

C. Continuous Kilns [8, 10]

(1) *Throughput.*—With continuous kilns of all types the principal saving of fuel is to be effected through increased rate of firing as far as the character of the material being fired and the product will permit. The efficiency of firing is largely dependent on the throughput as can be shown by graphs on which are plotted the fuel consumption per ton of product and the output. Kilns should be operated at their maximum output or rates of fire travel, or at or above their rated capacity. Many of the factors outlined below effect fuel savings because they lead to increase of throughput as well as reducing heat losses.

(2) *Condition of Kiln.*—Kilns should be kept in good repair with air leakage reduced to a minimum, flues clean, dampers or bells properly seated, wickets tight and the end of the setting in the circuit effectively sealed with papers. Foundations should be substantial and well drained, and preferably the kiln should be roofed over. When kilns are in poor condition the major source of heat loss is that due to air infiltration, i.e. through cracks in the kiln structure, particularly at and around the wickets, at feed-hole seating blocks or lids, through spaces around damper control rods or at sliding damper plate positions, at the main damper, at the paper over the end of the setting, etc. Inleakage at these or rather some of these positions can have a significant effect on the firing, the rate of fire travel and the fuel consumption.

(3) *Setting.*—The setting should be carefully carried out, with bricks properly spaced apart, flues aligned, with charge shafts directly under feed-holes, etc. With car tunnel kilns excessive space at the sides and over the top of the setting should be avoided, so as to make the gases travel through the setting.

(4) *Number of Chambers.*—With Hoffmann and related types of kilns the length of fire travel round the kiln should be sufficient to give satisfactory working. Kilns with 18 to 20 chambers are preferable : 12 to 14 chambers are considered to be too few for fast rates of fire travel and for suitable operating conditions for the men. The longer kilns permit better firing circuits to be maintained, with consequent better heat recovery, allow for hot-air drying on the kiln and provide cooler conditions for the workmen in the setting and drawing chambers.

(5) *Moisture Content.*—Dry goods can be fired at faster rates than wet goods and at lower fuel consumption on the kiln. However, although the fuel consumption on the kiln may be reduced by drying the bricks externally in dryers, the total fuel consumption for drying and firing may be increased. For certain

types of ware it is desirable to dry the goods thoroughly before placing in the kiln if the production of faulty ware is to be limited or avoided.

(6) *Frequency of Firing.*—With top-fired kilns small charges of coal should be fed at frequent intervals, e.g. every 10 to 15 minutes. With grate, side-fired, kilns of the Belgian type, intervals of 20 to 30 minutes should not be exceeded. Feeding heavy charges of coal particularly at the back of the firing zone on top-fired kilns of the Hoffmann type generally gives rise to the production of the heavy residues of unburnt fuel or cokes which are found in the chambers when the bricks are drawn. Wet fuel may conveniently be dried off on the kiln top prior to firing.

(7) *Mechanical Stokers.*—With top-fired kilns fitted with mechanical stokers, a saving of from 10 to 15 per cent. is claimed over hand firing, together with increased speed of fire travel. In general, the coal consumption for firing common building bricks is of the order of 2 to 6 cwt. per 1,000 bricks. For very carbonaceous clays the consumption can be lower than 2 cwt. From practical and economic points of view the use of such stokers for firing building bricks is best limited to those made from non-carbonaceous clays where the fuel consumption is at least above from 3 to 4 cwt. per 1,000 bricks.

(8) *Available Draught.*—The stack should be of sufficient height to give the required draught to operate the kiln at a satisfactory rate, and flue sizes should be such as to offer no undue restriction. On Hoffmann, Belgian and related types of kilns, generally stack heights of 120 to 150 ft. appear to be satisfactory for operating at the rates of fire travel normally employed in this country, except in exceptional cases with very large kilns where the height may be 200 ft. or so.

Induced draught fans are employed where higher draughts are used (on certain zig-zag kilns) and should prove of benefit on kilns where the draught is sluggish. The fans provide a more constant and, if required, higher draught, and waste gases may be exhausted at lower temperatures than when stacks are employed. The efficiency of operating the kiln will therefore be increased. On the other hand the fan running continuously, with electricity at 1*d.* a unit, will cost about 1*s.* an hour to run, or approximately 1*s.* 8*d.* per 1,000 bricks on kilns producing 100,000 building bricks per week.

(9) *Insulation.*—Continuous kilns of the Hoffmann, Belgian and chamber types rely on the thickness of the walls and crown to keep down the heat losses by radiation, convection and conduction. Side walls are usually 5 ft. or more thick and the depth of material over the crown 2 ft. or so. Although the heat stored in the kiln structure is high, use is made of it to some extent in heating the air for combustion, heating the air used for pre-drying in the kiln, and heating the green goods freshly set in the kiln. High structural strength is required of these kilns to limit cracking of the structure which would permit air inleakage. Insulation is occasionally applied to chamber kilns firing to high temperatures.

On the other hand, with continuous car tunnel kilns insulation is more or less essential because of the length and large surface of the kiln. Such kilns can be well insulated throughout their length particularly in the firing zone, both in the side walls and crowns. Car bases also may be insulated.

(10) *Firing Circuits.*—Fuel savings may be obtained by maintaining a good firing circuit. Thus with Hoffmann and chamber kilns the circuit should be kept constant as far as possible, with a given number of chambers cooling, firing, preheating and drying with hot air. Chambers of freshly set goods

should be taken on singly, and the whole circuit moved forward one chamber in a given time. Good practice is to maintain 4 to 6 chambers cooling behind the fires and a similar number of chambers preheating in front of the fires, and maybe 2 to 3 chambers drying with hot air. Emptying chambers too near the firing zone allows excessive amounts of air to rush through the few remaining chambers of cooling bricks without being properly preheated—extra fuel is then required at the back of the firing zone to prevent undue cooling. In the preheating zone dampers are often raised on chambers too near the firing zone—in consequence gases are exhausted at a higher temperature than they should be and before they have done as much work as they might in preheating the goods in forward chambers.

(11) *Control Instruments.*—Control instruments are as necessary on continuous kilns as on intermittent kilns, but they are mainly seen only on car tunnel kilns. These are usually fully instrumented with pyrometers and draught indicators or recorders. More detailed information on the firing schedule on car tunnel kilns can be obtained with travelling thermocouples.[11]

For all types of continuous kiln, pyrometers, draught gauges, and a gas analysis apparatus or CO_2 portable indicator or recorder should be available. In all cases it is desirable to know the temperature and analysis of the waste gases at the base of the stack or at the fan. Pyrometers are not only useful to control the firing but also prove useful when used in conjunction with the other instruments, in overcoming troubles such as difficulty in attaining the maximum temperature or maintaining the rate of firing, discoloration of the goods, the production of cracked ware, etc.

Gas producers for firing car tunnel kilns and chamber kilns should be fully instrumented—e.g. gas-outlet pyrometer, steam/air blast temperature indicator or recorder, gas-pressure gauge or recorder, rods to measure the depths of the ash and fuel bed, etc., and a gas analysis apparatus to determine the quality of the gas when desired. The quality of the gas can soon fall off if instruments are not used to regulate the working of the producer.

FUTURE TRENDS

The future trend of firing is undoubtedly towards extending the use of continuous kilns in both the refractories and heavy clay industries. With this extension, economies in the use of fuel will necessarily follow. There can be no doubt that both the tunnel kiln and the chamber type of continuous kiln possess their own individual advantages. The modern car tunnel kiln, for instance, makes efficient use of fuel, the firing conditions are under good control, it facilitates a straight-line layout of plant and allows setting and drawing to be carried out under good conditions. The chamber type of continuous kiln uses fuel in a very efficient manner.

There are certain products which in our present stage of development are difficult to fire in the continuous kiln. Such products include the salt-glazed pipe, the blue engineering brick and, in general, the roofing tile. Much urgent research is required in the firing of such products. At the present time and for some time to come, firing in the intermittent kiln is inevitable, either in consequence of the nature of the product or the size and outlook of the works. The possibility of inter-connecting such kilns should not be overlooked. Further savings may be possible by the use of insulation (preferably hot-face insulation) and, in some cases, the use of the mechanical stoker.

For the provision of power a tendency towards the increased purchase of electricity may be noted. This is certainly the case with works, the products of which do not have to be dried prior to firing, such as stiff plastic, semi-dry-pressed and dry-pressed products. The relationship between the utilisation of steam and electricity on many works is a matter for careful study.

Throughout the industry a greater tendency to make more use of control instruments, especially in the firing operation, may be noted. In addition to draught gauges, the value of the recording pyrometer and carbon dioxide indicator are well recognised.

On the more progressive works thought has been or is being given to the various points raised above. Many of the larger and more modern works in the various branches of the heavy clay and refractories industries make very efficient use of their fuel. Continuous kilns are by design efficient. Where continuous kilns are used with electric drive to plant or with up-to-date steam plant, efficient fuel utilisation is generally being obtained. Thus the many common brickworks distributed throughout the country of varying size, which employ the stiff-plastic or semi-dry-pressed process of manufacture, having a continuous kiln or kilns and driving the plant by purchased electricity must by their very design be efficient users of fuel : minor economies may, of course, be effected here and there but these can only be regarded as of small concern. There are, of course, firms which have progressively expanded from small beginnings, where modernisation of plant, more particularly steam plant, could be carried out with benefit.

Acknowledgment

The author wishes to thank Mr. A. T. Green, O.B.E., Director of the British Refractories Research Association, for his interest in the preparation of this paper.

Discussion

Mr. P. Williams (Lord Mayor of Stoke-on-Trent) said that the prosperity of the area he represented was dependent upon that of the clay industries and depended upon those industries being efficient. The City of Stoke-on-Trent, because of the demands for efficient tunnel kilns, had been caused to undertake considerable development to meet the demands on its gas and electricity undertakings. They were studying the problems and requirements of the industries and in so doing were helping to ensure future progress in which both Stoke-on-Trent and other towns would share.

Mr. S. R. Hind pointed out that the very low theoretical efficiency of even the best continuous kiln as disclosed by Mr. Dinsdale's analysis indicated the great possibilities that existed for fuel saving in the future. Two features which required attention in the future were the insulation of kiln walls and the recovery of the sensible heat of the finished ware. These losses, which were related to the time-cycle and to the setting density of the ware, could be tackled by tunnel ovens. The co-operation existing between the gas and electrical undertakings at Stoke was enabling the industry to explore the technical possibilities of the two methods of firing. Glost ware could be fired electrically without saggars ; with town gas the conditions were more critical, but excellent results had been obtained with electrical porcelain and the ordinary type of low-sol lead glass, though not with leadless glaze. Every improvement in insulation and recuperation helped by reducing the violence of the sweep of the gases over the maturing glaze, thus protecting it from an undue loss of volatile constituents. Moreover, only fortuitous circumstances had so far prevented an equally high setting-density of ware in gas-fired kilns as that used in electric glost tunnels ; unless this had been achieved, electricity would have remained far more costly than gas.

Mr. Rowden's excellent report gave room not only for thought but for anxiety. It appeared that works making roofing tiles, blue bricks and salt-glazed pipes were still not in a position to adopt that economy in fuel and freedom from smoke which the community so badly needed ; investigation was called for to produce a product, modified if necessary, capable of rapid, continuous and economical firing without smoke. Mr. Rowden's review of the heavy clay product led to the conclusion that the great obstacle to reduction in fuel consumption was the generally protracted firing and cooling time.

Colonel Gibbons said that success with tunnel kilns depended very much on the choice of fuel. While agreeing with Messrs. Lockett and Bullin's paper in general, he disagreed with the statement that saggars were necessary when using town gas ; this statement ignored gas-fired muffles. The same light-weight supports could be used for gas firing as were used for electric firing. While intermittent muffles were expensive in gas consumption, continuous muffle kilns were not, and showed little higher consumption than open-fired kilns. During the next five years, electricity, he believed, would be used primarily for small outputs and expensive ware, and gas for large outputs and less expensive ware. Oil was an admirable fuel especially where prices for gas were higher than those ruling at Stoke-on-Trent. There should be close co-operation between kiln-builders and users. There was need for technical research on refractories and burners, on electrical resistors, and to reduce the weight of kiln furniture, and to supply data on the smallest type of continuous kiln that could be used successfully. There was very little information on the speed at which ware could be fired under uniform heating conditions and until such knowledge was available it was not possible to determine the minimum kiln size to provide a given output.

Mr. D. L. Wilson maintained that improvements could be made in the design of the continuous kiln for dealing with materials requiring high temperatures and difficult firing schedules, such as silica bricks, since it was not always possible to reconcile requirements for large blocks and smaller ware, as could be done in an intermittent kiln. If the obstacles in the way of doing this were carefully defined, they could be overcome. He agreed with Mr. Rowden's view of the effect of using poor quality coal. At one of the works of General Refractories, Ltd., a soft ganister coal had been supplied containing up to 70 per cent. below ½ in. ; the coal was screened through a 1 in. mesh and the material passing through this screen was bonded with tar into briquettes which were used in conjunction with the over-sized coal. In this way the fuel consumption was reduced from 13 cwt. a ton of saleable goods to 9 cwt. Their later development in stoker-fired kilns had further decreased coal consumption to 7½ cwt. a ton as an average of 18 burns on silica goods. If coals were graded or briquetted, the quality of the fuel required for firing to temperatures of 1000°–1100° C. was not very important. For higher temperatures a high ash-fusion temperature was desirable for this method of stoker firing. With the advantage of both fuel control and air control they had found little difficulty in varying the kiln atmosphere from 12 per cent. to 18 per cent. CO_2 at 1000° C. The new kiln offered possibilities of providing full insulation, and direct savings were made because the twelve separate fire-mouths had been eliminated. In a later kiln the stack was only 20-ft. high and it was working well. There was a big future for inter-connected intermittent kilns with well-insulated flue systems.

Mr. Muir referred to practice at the works of the Consett Iron Company, Ltd., where many different kinds of silica blocks were made, varying in weight from 4 lb. to 1 cwt., together with sillimanite and magnesite bricks. They had originally used four 32-ft. kilns, holding 180–200 tons of goods and the fuel consumption was 9–10 cwt. per ton of goods. By adding waste heat boilers a saving was secured equivalent to 35 per cent. of the fuel used. Recently, the Company had erected fully-insulated kilns in which the fuel consumption had been reduced to 7–8 cwt. Basic bricks had been fired at 1600° C. in a tunnel kiln using the waste heat for drying. Gas-fired chamber kilns had been found satisfactory for bricks but not for shapes and large blocks, and more down-draught kilns would be built for firing these products. There was difficulty in obtaining coal having ash of suitable fusibility for automatic stokers, and fly-ash adversely affected silica products. Each of the Consett kilns was fitted with a permanent thermo-couple with 6-point recorder. Because of the quantity required (2 million cu. ft. a day) it was not possible to fire with coke-oven gas alone, but if coal prices continued to rise, consideration would have to be given to the use of coke-oven gas and oil.

Mr. M. Roddan said that one of the major advantages of the continuous process was that the heat expended per unit of ware fired was reduced, taking Mr. Stanier's figures, to somewhere about $\frac{1}{4}$ to $\frac{1}{8}$ of that required with hand-fired coal on an intermittent kiln. This saving was, however, only possible by using some form of controlled heat which permitted of considerable reduction in the time of firing by virtue of accurate and steady control of the rate of temperature rise throughout the firing period.

On an intermittent hand-stoked kiln the temperature at any point in the kiln rose in a series of waves having the same periodicity as the intervals of firing. The rate of temperature rise during the time of maximum heat release from the fire must be controlled to prevent damage to the ware, and therefore if a controlled fuel was used the waves in the temperature curve would not occur and the average rate of temperature rise could be the same as for the short period of maximum heat release in the coal-fired job. This gave a very much shorter time cycle with a corresponding reduction in fuel consumption.

From records of conversions of this type of kiln to oil in this country and abroad it appeared that the thermal input was only about half that on hand-fired solid fuel and on this basis each ton of oil would replace about 3 tons of coal. The national interest would be better served by using 1 ton of imported oil to replace 3 tons of coal on intermittent kilns than to replace 1$\frac{1}{2}$ tons of coal on boiler firing.

From the consumers' viewpoint at today's prices for oil in the potteries, coal would have to be delivered at about 42*s*. per ton to equal oil on the above assumption without making any allowance for labour saving in stoking. Further, the reduced firing period would automatically increase the output capacity of the kilns.

Mr. W. C. Colclough referred to the difficulty of applying "yardsticks" for fuel consumption to this industry because of the diversity of its raw materials and products ; Mr. Dinsdale had set a target and the other speakers had shown from the practical angle how it was being approached. All these speakers, however, had used very different bases of comparison and it was very desirable for there to be a standard method of reporting results ; he suggested that it should be in " therms per ton ", and that the efficiency of any process should be defined as the ratio of the possible and actual fuel consumption for the particular raw material and plant in use ; in all this, the conversion factor for the fuel should be considered.

Mr. W. Noble believed that the co-ordination of interest which had been shown between suppliers of plant, users and research workers augured well for balanced progress in the industry. Among the large number of factors which went to make up maximum thermal and economic efficiency, he classed as of outstanding importance : the employment of skilled firemen who would make full use of control equipment ; using the right fuels and kilns for the firing conditions required ; getting maximum output from the kilns consistent with a high yield of good quality products ; and control of excess air and waste gas temperature. Direct advantages arising from increased output per kiln were reduced overhead and labour costs as well as reduced fuel consumption. The fuel consumption in continuous kilns involved two main factors, namely (1) fuel equivalent of the heat requirement of the goods, which for a particular product was constant per ton of ware and (2) the fuel equivalent of the heat losses from the kiln and flue structure which, under steady conditions of operation, was constant per unit of time. Unavoidable waste-gas losses could be associated with each of these factors to provide a theoretical relationship between them and fuel consumption. This relationship showed that when low outputs prevailed increase in output could have a greater influence on fuel consumption than any other single factor.

Mr. H. Oliver pointed out that the continual increase in efficiency of industrial high-temperature operations would necessitate improved refractories, and that these could only be produced by firing under such closely controlled conditions as to give the maximum possible uniformity of heat treatment throughout the setting. Firing efficiency and fuel economy were found at his works to be adversely affected to a marked degree when the fuel used was unsuitable. The speaker agreed with Mr. Colclough's suggestion that there should be a standard method of reporting fuel consumption and in view of the variation in the quality of fuels suggested that it should be on thermal units rather than on weight. At the Friden works of Derbyshire Refractories, Ltd., siliceous and silica products were both fired in semi-continuous (to 1370° C.) or continuous (to 1400° C.) chamber kilns, both being maintained at these maximum temperatures for a considerable period. Due allowance should be made for this factor in addition to the heat required to raise the goods to a maximum temperature when an attempt was made to assess the thermal efficiency of the kiln firing process. At Friden the fuel used was approximately 4½ cwt. a ton fired-weight of net siliceous goods as set, and 8 cwt. for silica. Improvements made with advantage in the past were the installation of mechanical stokers, coupled with temperature-recording instruments and the insulation of the arches, and walls, wickets, etc. The importance of careful training of the operators to handle modern equipment could not be over-emphasised.

Mr. Felson referred to the difficulty in persuading firms to experiment with mechanical stokers. He suggested that the application of mechanical stokers should be part of the research programme of the appropriate research association.

Mr. Forse emphasised the importance of insulation by reference to a tunnel oven in which the consumption of town gas had been reduced by 10,000 cu. ft. a week by adding 4½ in. of insulation ; a further 10,000 cu. ft. a week had been saved by re-designing and insulating the firing zone ; further improvements were now to be made to this kiln. It was probable that a much higher efficiency would be maintained if the air from the cooling zone were returned to the tunnel.

Mr. V. Davis compared the absence of control instruments in the clay industries with the elaborate methods of control exercised in some other industries. He believed that much could be done towards better coal handling. Discretion should be exercised in using electricity for heating new kilns, since the electricity supply industry could not today meet the demands made upon it. He believed that many firms, after considering their heating, drying and power requirements, would find that the thermal balance was favourable to the generation of their own current.

Mr. Lobley said that electric furnace manufacturers had been working on the development of heating elements but were not very hopeful of developing metallic elements for temperature work. Non-metallic elements, though fairly good, were not entirely satisfactory and were not manufactured in this country. Small electric furnaces were proving economical both in space and time and were of value on small works.

Mr. Gosspard suggested that greater attention should be paid to fitting the load to the shape of the furnace, and to taking the fullest advantage of all available placing of space ; this would increase throughput considerably without increasing the quantity of fuel used in proportion. Improved thermal efficiency could be secured by using lighter (hollow) sections and perforated bricks. He thought there was little justification for making solid bricks.

Mr. T. C. Bailey appealed to users not to instal oil-burning equipment indiscriminately but to reserve it for purposes for which its special characteristics best fitted it, such as biscuit firing in the pottery industry and in the manufacture of high temperature refractories. The manufacture of common building bricks was probably not the best use for oil fuel. He asked for a spirit of friendly co-operation and healthy competition between all fuel suppliers, with collaboration in overcoming users' problems.

Mr. Butterworth questioned the need for the prevailing practice of using blue bricks and suggested that other types of brick could meet the British Standards Specifications for engineering bricks of grades A and B which would be less expensive in fuel consumption for manufacture. In dealing with heat losses from kilns, considerably more attention should be paid to the recuperation of heat from beneath kilns, both for increasing efficiency and protecting the foundations. Trouble had been caused when kilns had been closed down for a long period by water returning to replace moisture which had previously been dried out from below the foundations, with the result that structural defects had developed to kilns and chimneys. Insulation alone was not sufficient because of the great depth to which heat could penetrate and the significant effect of even moderate temperatures.

Colonel C. W. Thomas (Chairman, The British Refractories Research Association) said that in the refractories and heavy clay industries fuel was consumed for three main purposes, (1) power, (2) drying the moulded products, (3) burning the dry products in kilns. The requirement for power and the conditions of its use were much the same as for other industries. In drying and burning, the greatest possibilities for economy lay in continuous operation under close control. Whilst this had been recognised for burning it had not been equally recognised for drying.

About half the products of the refractories industries consisted of standard bricks not exceeding 13½ in. × 6 in. × 3 in., the bulk being 9 in. × 4½ in. × 3 in. and under; the remainder comprised blocks of various, and sometimes very complicated shapes, and sizes varying from a few pounds to 6–8 cwt. each. Since the drying process involved the transmission of moisture from the interior to the exterior of the block, and the burning process involved the transmission of heat from the exterior to the interior, uniform conditions of heat application, and therefore of fuel consumption, were not possible. In the speaker's view much of the existing inefficiency in the industry was due to failure to distinguish between the processes of drying and burning and to keep them quite separate. In the intermittent kiln, for example, it was impossible to remove all the water of manufacture before the goods were set in the kiln because if moisture-free they would be too brittle to handle. Since they were set in the kiln while still containing 10 per cent. of moisture, the first operation in the kiln must be that of drying, and only when this was completed could burning commence. Only in the 'car and tunnel' kiln was this difficulty overcome; the goods, set on kiln cars, passed through a tunnel dryer and thence to the kiln proper without further handling. It was, however, rarely possible to instal tunnel kilns in existing works without sacrificing many of the advantages derived from the existing works layout and therefore some other type of kiln often had to be selected.

The most economical type of plant for moisture removal was some form of progressive humidity dryer in which the ware was not subjected to rapid drying until its temperature had been raised to a uniform degree throughout; when this was done, the moisture content of the air in the dryer could be lowered and comparatively rapid drying would then take place without risk of cracking. A chamber type was recommended in which a number of adjacent chambers were progressively filled with the green ware and progressively heated in succession, the drying rates being regulated in proportion to the temperature of the chambers.

Only by the adoption of continuous burning kilns and continuously operated dryers could there be achieved any considerable reduction in the fuel consumption. Figures quoted in Mr. Rowden's paper had shown that the fuel consumption was something like six times the amount required to raise the product to an average finishing temperature of 1300° C. When all allowance was made for inevitable losses and even for all possible improvements in kiln design and operational control, there would still remain a wide margin of possible savings. There was a wide field for investigation here, including improvement in design and more exact operational control, and the British Refractories Research Association was preparing to enter into this branch of research in the near future.

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SECTION F.

SPECIAL INDUSTRIAL SESSIONS—*continued*

SESSION II. The Railways

Chairman of Session: MR. V. M. BARRINGTON-WARD
DIVISIONAL MANAGER, SOUTHERN AREA, L. & N.E. RAILWAY COMPANY

1. The Design of Steam Locomotives in Relation to Fuel Efficiency

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An attempt will be made in this paper to concentrate only on those problems on the locomotive which are of the greatest significance in relation to the saving of fuel. It will not be possible to touch upon locomotives of other than conventional design, but the restriction of consideration to these types alone is amply justified in the light of the fact that by far the greatest proportion of the fuel burnt is consumed in such locomotives. By standards applicable to stationary steam practice, particularly in large electric power stations, the conventional steam locomotive has not a high thermal efficiency. It is also far surpassed by its rival the Diesel engine, whose first cost, however, and greater mechanical complication render the ultimate economic benefit much less than that due alone to its greater thermal efficiency.

In the consideration of a projected design for a steam locomotive the usual conflict between a desirable high thermal efficiency on the one hand and a specified high rate of energy output on the other hand is soon joined. In the steam locomotive the rate of combustion is inextricably interwoven with the rate at which the engine is using steam, because the exhaust steam in passing through the smokebox entrains air and thus creates a draught through the flues and hence through the firegrate. The higher the steam demand, the greater is the weight of exhaust steam, and consequently the heavier is the draught on the fire. This results in an almost automatic adjustment of the combustion rate to meet the variations of steam demand, but the heavy draught induced when working under maximum load conditions exercises a pronounced disturbing effect on the fire. The inevitable result is a progressive increase in the rate of loss due to unburned fuel being lifted from the fire through the tubes of the boiler as the steam-using rate increases. Hence the point at which the maximum possibility of high fuel efficiency exists, namely the firegrate, is the same point at which the necessity for a high power output produces the most serious adverse effects on the fuel efficiency. It may be of interest to interpolate here a comment on oil-fired locomotives, of which the Great Western Railway have had some experience during recent months.

Compared with a coal-fired locomotive the oil-fired engine exhibits a very much more rapid steam raising following an increase in the firing rate, due to the almost instantaneous combustion of the oil. Owing to the absence of the coal burner's firebed, however, which is immediately responsive to increased draught following enhanced steam consumption, the oil burner requires very close control of the rate at which the oil is fired to keep step with fluctuations in steam demand. At the highest rates of combustion, which incidentally can be sustained for lengthy periods owing to absence of dependence upon manual handling of the fuel and liability to choking the fire, the unburned fuel loss with the oil burner remains at zero, in strong contrast to the coal burner.

Returning to consideration of the effect on the various losses due to the interdependence of steam demand and combustion rate in the steam locomotive, the high combustion rate under the optimum conditions which release large quantities of heat energy destined in theory to be transferred to the water in the boiler, causes increasingly large losses in this transmission of the heat to the water. Also the normal loss due to the ejection of large quantities of hot flue gas from the chimney is inevitably increased when working at high capacity.

In consideration of design strictly in relation to fuel efficiency, the ultimate criterion of performance must, of course, be the ratio between the drawbar horsepower of the locomotive and the corresponding rate at which British Thermal Units are fed into the furnace in the fuel. The net result of adopting such a criterion, however, is the contemplation of a figure which varies between 6 and 9 per cent., the latter obtaining only with the best modern designs. Compared with the 20 or so per cent. possible with steam turbine generator station practice, this figure appears extraordinarily low, but it must be emphasised again that the steam locomotive of the conventional design, whose virtues of simplicity and cheapness have been long proved beyond question, operates over a restricted temperature range and must of necessity contain, within the very small space appropriate to the loading gauge of the railway upon which it has to run, all the essential elements of the power station. Within these limitations, therefore, the designer of the steam locomotive must concentrate on each stage of the flow of heat from the unburned fuel to its ultimate destination and restrict to the minimum those inevitable losses which occur. These are :—

(1) Losses in combustion, which generally take the form of unburned fuel passing through the grate into the ash pan or being lifted through the tubes into the smokebox.

(2) Losses by hot gases passing from the chimney and radiation losses from all surfaces of the boiler.

(3) Losses in the cylinder due to impossibility of adhering to the ideal thermodynamic cycle between the temperature limits over which the engine is working, and

(4) Losses in the mechanism of the machine in moving itself over the road.

Each of these causes of wasted heat must be examined with a view to minimising the quantity of heat so lost, but any refinement evolved to minimise loss must be such that it will function correctly over the widely varying conditions under which the locomotive may be called upon to work. In order to emphasise the extent to which the limitations of space and weight on the one hand, and the restricted temperature range over which the locomotive is working on the other hand, restrict the opportunity for achievement of the maximum thermal efficiency, some comparisons with stationary steam practice reveal striking apparent anomalies. For example, it is standard practice to equip a stationary plant with economisers, thus removing from the hot gases in the exhaust passages valuable heat which is used to raise the temperature of the water. No such practice has been found to be possible on the steam locomotive. Feedwater heating on locomotives, however, is extensively in operation through the medium of the exhaust steam injector and the measure of thermal advantage resulting from the use of this appliance is appreciable. Again, preheating the large quantities of air necessary for combustion by some form of air preheater is a common practice in stationary plants. The great complication and size of such a plant on a steam locomotive prohibits its use. Superheaters situated only in the smokebox, thus taking heat from the exhaust gases only, have not found great favour owing to their restricted capacity, and the superheating which is extensively adopted is achieved at the expense of some sacrifice of evaporative heating surface. Lastly, and most important, stationary practice involves almost without exception the use of a condenser, with consequent reduction of the back-pressure loss. Condensing locomotives, however, have not up to the present been found to give very satisfactory service.

It remains, therefore, to demonstrate to what extent the remaining fuel losses have been successfully minimised. The design of firegrate and of the damper gear controlling the entering air have been the subject of close study for many years, with the result that all well-designed locomotives have the loss which is due to excess of air in the flue gases reduced to very small proportions. Similarly, intensive study of the problem of transferring the heat from the hot flue gas to the water in the boiler has resulted in a transmission rate equal to many of the most advanced water-tube designs. Again, the thermodynamic advantages due to the use of superheated steam are widely recognised, and all but the smallest locomotives are equipped with superheaters. Finally, the closest attention is paid to the events in the cylinder itself with the result that the ratio between the actual work performed in the cylinder to that theoretically possible compares favourably with a similar comparison with any stationary practice. It can, then, be contended that modern designs of conventional steam locomotives exhibit high standards of excellence in fuel efficiency within the physical limitations of dimension and the thermodynamic limitations of temperature range under which they work. In conclusion, however, it must be stated that as it is a machine intended for transportation duties over roads with widely varying gradients and with widely varying loads, its rate of performance fluctuates over a wide range and, ultimately, its success as an efficient fuel-burning appliance lies largely in the hands of those who are operating it.

2. Locomotive Operation in Relation to Fuel Efficiency

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The first question that arises is what one means, in this connection, by the term " fuel efficiency ". The engineer might ask how many pounds of steam are produced in the boiler for each pound of coal burned in the firebox when the engine is working steadily ; he might ask how many foot-pounds of useful work each pound of coal produces at the drawbar. I suggest that from the point of view of railway management the vital feature is the number of tons of freight, or the number of passengers, carried a given distance for each unit quantity of coal for which the company has to pay ; or taking a rather wider view, that it is the average cost of fuel, as delivered to the tender, for each unit of traffic moved a given distance.

The four main line railway companies in the past year had to pay for about 14½ million tons of coal for locomotive use—this is about 8 per cent. of the country's total coal production. They naturally want to get the greatest possible amount of work from the least possible quantity of coal, for two very good reasons : the coal is very expensive, and the most suitable grades for use in locomotive fireboxes are in short supply.

There are a good many circumstances which affect the amount of useful work we get from a pound of coal, and I have selected five main headings—they are not exhaustive, and not necessarily in order of importance :—

(1) The use of the locomotive as a traffic unit, by which I mean the way it is used from the time of departure from a running shed until its arrival at the same or another shed on the completion of its work.

(2) The design of the locomotive.

(3) The workmanship displayed by both members of the crew.

(4) The maintenance of the locomotive in good condition.

(5) The quality of the fuel.

One is sometimes asked, especially of a new type of engine, how much coal does it burn ? There are usually quite a number of different answers to this question, because a locomotive—let us suppose it is of a mixed traffic class—will burn one quantity of coal per mile when it is working a non-stop passenger train and an entirely different, and much greater, quantity per mile when hauling a heavy stopping train over adverse gradients.

A locomotive which in the summer will work a non-stop run of 250 miles with a load of 300 tons, on an actual coal consumption of 27 lb. per engine-mile, may yet show a consumption of over 60 lb. per mile when averaged on all the services for which it is required over a period in the winter months when weather is bad and steam heating is in use. In fact, as hardly any two booked workings are identical in the loads of the trains, speeds, or station stops, the coal consumption of a locomotive varies with every different working for which it is used.

Economy of coal burned in performing each useful ton-mile of work depends perhaps most of all on careful planning—assuming, of course, that the planning is duly translated into practice—and on the provision of the right kind of engine for the work it has to do. One might go back further, and say that it depends essentially on close co-operation between the locomotive and operating departments of the railway.

The efficient planning of the locomotive's work includes not only keeping the engine in traffic for the greatest possible portion of the 24 hours, but also keeping it doing useful and economical work during that time. This means in turn that the train service should be arranged with an eye on the availability of locomotives to work it ; that unnecessary stops should be eliminated, because they account for the consumption of a good deal of coal, and that a good deal of attention should be paid to suitable timings for each section of the road. There is little benefit in working an engine very heavily on an adverse gradient to save a minute or two which could quite easily be saved in some other section of the road.

The arrangement of each day's work for a locomotive is usually set out in some kind of diagrammatic form, and the preparation of these diagrams is a highly specialised job. The trains included in each one should make approximately similar demands on the locomotive, because a very powerful engine working a light train, or a small engine trying to handle a train not really within its capacity, are both wasting coal.

Nevertheless, the provision of an engine powerful enough to do its work at an economical rate of steam expansion is very important. One of the advantages of the steam locomotive is said to be its ability to handle overloads. So it is ; but the locomotive has a great capacity for suffering in comparative silence, and overloading is a cause not only of maintenance troubles, but also of poor fuel efficiency figures. Even when an engine can keep time with no apparent discomfort, it may not be powerful enough to register the most economical coal consumption, through having to work at too low a rate of steam expansion. In a trial between two highly efficient locomotives with tractive efforts of 22,000 and 32,000 lb. respectively, working the same train under identical conditions—it weighed 275 tons and made several stops—the more powerful engine burned 30 per cent. less coal than the smaller one. There are numbers of insufficiently powerful locomotives on all railways, and we are all trying to bring our stock up to date by new building of better engines as fast as present circumstances will allow.

Overall fuel efficiency is very much influenced by the actual conditions of traffic working. Signal stops—especially on adverse gradients—detention in sidings, distant signal checks, permanent or temporary speed restrictions, all waste the energy of the moving train, and cause extra work to be done in setting it in motion again and in regaining speed. It is a truism to say that this extra work can only come from the fuel burned in the firebox.

The companies are making great efforts, in the face of many still existing difficulties, to restore pre-war speeds on passenger trains. It might be thought that as the speed goes up the coal consumption goes up too, but this is only true within limits. An engine working steadily at an economical rate of steam expansion and with few stops is burning coal most efficiently ; and leakage losses past piston and valve rings, which are perhaps rather larger than is generally realised, become less important as the speed rises.

The average coal consumption per engine-mile on the four main line railway companies has increased considerably as compared with pre-war figures. This is due to several causes, one of which in particular is mentioned later, but it is by no means a measure of decreased efficiency of operation. The great efforts which have been made to increase the average load in each wagon and the average number of wagons in each train—within the limits, of course, of the economical capacity of the engine to haul them—increase the amount of coal burned for each train mile ; but they also increase efficiency, since by reducing the number of trains needed for a given volume of traffic, they also reduce the amount of coal burned for each ton-mile of freight moved. The efforts of the operating departments in reducing congestion and consequent idle time of locomotives, or in reducing shunting miles at marshalling yards by the adoption of through block loads, are direct factors in increasing the efficiency obtained from the total quantity of coal burned on freight work.

We look to the designers of locomotives to provide us with machines which are reliable, and of ample power for the work to be done ; and we expect to be able to make full use of higher boiler pressures, and a high rate of steam expansion, without risk of damage to the mechanical portions of the engine. The stock of the main line companies is steadily being renewed, and no doubt these renewals will be accelerated as the general position becomes easier ; in the meantime, older classes of locomotives have often to be worked at a rate of steam expansion too low for the most efficient results, and with the steam chest pressure below that in the boiler—throttled, of course, by the partial closing of the regulator—in order to prevent heating of big end bearings or the development of knock in the axleboxes.

Given locomotives of suitable design, the workmanship displayed by the driver and fireman can have a considerable bearing on the efficiency to be obtained from the coal. The difference in coal consumption to be obtained with a modern engine by the driver, as between present-day and older methods of handling his locomotive, is of the order of 15 per cent. ; but there can be no doubt that good results are obtained today by our highly experienced footplate staff. The fireman's workmanship also has a good deal of influence on the efficiency with which the coal is burned. When a locomotive is worked at a more or less constant rate, the best results are undoubtedly obtained by a complete regularity of firing, which may show an advantage over less methodical habits of as much as 9 per cent. Nevertheless it is hardly safe to be dogmatic as to the precise methods which ought to be used in all cases, because all locomotive work is not of the kind just mentioned. By far the greatest number of our engines is engaged on mineral, freight, branch or suburban passenger work, local colliery and goods trips, or on shunting. In these there are widely varying demands on the boiler, and the method of firing must be adapted to existing conditions. All firemen are instructed in the principles of combustion, and are trained, both by precept and example, in proper methods of workmanship ; but complete mastery of their art can only be obtained through the hard school of a varied experience.

The conditions of mechanical upkeep which mainly affect fuel efficiency—apart from wastage of steam through leakages at joints—come within two main categories : the maintenance of valves and pistons in a steam-tight condition, and the correct maintenance of the valve setting. The first of these is ensured by regular examinations at the front end of the locomotive on a time or mileage basis ; the second by the checking over, and the correction, if necessary, of the valve setting at the time of these examinations, and by the correction of wear in main bearings at appropriate intervals. The valve setting is very important, since if the valves are out of truth the use of a short cut-off, which means fuel economy, is liable to cause trouble with big ends and axleboxes. The valve events are appreciably influenced by small amounts of play in the axleboxes, especially on older locomotives with short valve travel, or on long valve travel machines at high rates of steam expansion.

As regards quality of fuel, the existing locomotive stock of the main line companies was to a very large extent designed to burn the qualities of coal which could be obtained up to 1939, and so were the appliances by means of which the coal is handled. Of present supplies, not more than two-thirds can be described as large loco. coal, which was the pre-war standard. The rest is made up of smaller sizes of loco. coals, of house coals in various sizes, opencast, briquettes, and coke. These substitutes cannot be burned with the same efficiency as the coals for which the locomotives were designed, and a considerable increase in coal consumption is attributed to their use.

Discussion

Mr. Jarvis complimented the authors on putting so much practical knowledge into so little space. He agreed that there was little hope of a practical condensing locomotive. Higher steam temperatures might bring lubrication difficulties. In his view boilers larger in relation to the power unit were desirable. Figures per ton-mile could be very misleading and true efficiency could only be expressed in B.Th.U. per draw-bar h.p./hour. Tests on a heavy freight engine between the Nottinghamshire coalfield and London showed very considerable variation, the consumption, with present quality coal, being in the worst case no less than 65 per cent. greater than with standard coal. The standard coal before the war had a calorific value of 14,500 B.Th.U. per lb., and the present standard was 12,500 B.Th.U. per lb. The coal consumption per drawbar h.p./hour before and since the war showed still greater disparity, the figures being 3·12 and 3·87 lb. respectively. That was a measure of the increased quantity of coal burned solely due to the prevailing reduction of quality. To combat in some measure the effect of inferior coal, the L.M.S.R. had adopted the rocking grate, which broke up the clinker and maintained reasonably good combustion conditions.

Mr. Crime emphasised the need for good quality feedwater, the importance of skill on the footplate and the need for co-operation between locomotive and running departments. With present coal supplies more frequent re-fuelling was necessary. He stressed the importance of giving instruction to the younger firemen, both in classes and on the footplate.

Mr. H. G. Kerry gave figures of coal consumption for all the main line railways for 1923 (the first year for which he could find complete figures since the grouping of the railways), 1939 and 1945. The increase in lb. per mile, from 1939 to 1945, was 20 to 21 per cent. The reduction of consumption as between each of the four railways during the period 1923–1939 did not vary by more than 2 per cent. ; the increase in the period 1939–1945 did not vary by more than 2½ per cent. It was reasonable to assume, therefore, that the reasons for the decrease and increase in the respective periods were common to all the railways, and he suggested that the major portion of the increase was due to the inferior quality of the fuel. He emphasised the need for good maintenance and for cleanliness of all heating surfaces, internal and external.

Mr. T. Mathewson Dick asked designers to consider how they could provide a controlled draught on the fire and at the same time obviate the bad effects of lifting the fire and moving it forward, and all the other things that happened when the engine was working heavily. He suggested that the amount of actual fuel burned was less nowadays, or at least no more, than was burned at any time ; the trouble was that large quantities of dirt and stone were carried through the fire into the ash pan and smokebox. Therefore, he asked that, while low-grade fuels were supplied, they should be more thoroughly washed and screened. He asked that attention be given to arriving at an analysis figure to indicate the value of a fuel when burned in a locomotive ; the calorific value and the ash content did not give the information that was needed, nor did the volatile percentage. The substitute fuels had quite a bad effect on the footplate ; if the enginemen disliked a fuel because of its smell or its behaviour, results would probably be bad.

Mr. Hart-Davies declared that locomotive boilers in themselves had good thermal efficiency ; the low overall efficiency was due to losses in the power unit. Efficiencies should be expressed as coal per drawbar h.p./hour since the coal per ton-mile was dependent also on the conditions under which the loco. was used. Civil engineering restrictions on gauge and height imposed a handicap on the locomotive designers, the only unrestricted dimension being length.

Mr. Binns while agreeing that there was room for improvement in design, believed that over-loading was a common cause of fuel wastage. The weakest link, however, was the operative. One promising direction in which improvement could be sought was in the reduction of unburnt carbon in the ash.

Major Gould, having been a member of a fuel efficiency department in South America, where fuel was very expensive, urged that compounding was a means of effecting great efficiency in steam usage and consequently in fuel efficiency. Many years ago, he said, this country had taken up compounding with great enthusiasm, but in recent years it seemed to have been shelved. Inadequate space in present designs led to boilers of inadequate size and to the failure to develop condensing loco. engines. He suggested a 3-unit locomotive comprising (1) a power unit, (2) a boiler truck and (3) a condenser truck which together would give an efficiency equal to that of a stationary plant.

Mr. Turban suggested reconsideration of experiments made when coal was plentiful and cheap. Comparisons between power station efficiencies and loco. practice were not really helpful. More attention should be given to lagging and to roller bearings, mechanical stokers and compounding. Major Gould's 3-unit loco. would present difficulties in marshalling yards.

Mr. G. J. Gollin wrote that conversion of a locomotive from solid fuel to oil would produce satisfactory results, and a therm of oil would do at least as much work as a therm of coal did before conversion. Better results were secured in a plant designed for burning oil. Here burners and air control were designed to give intimate mixing of fuel and air with rapid and complete combustion, and 1 therm of oil did the work of 1½ therms of coal. In the loco. designed to be fired by solid fuel the shape of the combustion chamber and the space available for the burner gear were against oil fuel.

Mr. E. L. Smith wrote pointing out that considerable economy in fuel consumption could be made by reducing the dead load of railway stock. This could be done by the use of aluminium alloys, a striking example of which was the road transport of bulk liquids in tanks constructed of aluminium sheet mounted on cast aluminium alloy bearers, thereby enabling increased pay loads to be carried for the same engine fuel consumption. Considerable use was made of aluminium on the London Underground Railways.

Mr. R. M. Macfarlane wrote that while no drastic improvement could be foreseen in existing methods of handling solid fuel, oil-burning gear and its application could be considerably improved. As with solid fuel, to get the best results from liquid fuel careful planning was required both as regards methods of burning and traffic operation. It was also essential that oil-burning gear should be correctly installed and that the control gear should be such that the operators could manipulate it to get the best results. The operators must be trained to appreciate the totally different conditions required for burning liquid fuel. The men responsible for the maintenance of the gear must also understand what is required of it in action.

Mr. F. Strauss wrote drawing attention to three important matters requiring attention : (1) Arrangements should be made by Ministries, railway companies and trade unions concerned to introduce systematic and thorough training schemes in locomotive firing for the footplate staff. This was already common practice on the Continent. (2) Improved maintenance of engines was an urgent necessity, including steam joints, valves, pistons and other steam glands, blow-down cocks, and injectors. (3) The introduction of bonus schemes in the form of premiums for the footplate staff on the basis of savings in weight of coal below an agreed target figure based on the class and load of train and the time of year ; this scheme was already in force on many railways, especially on the Continent.

On all Continental and U.S.A. railways, loco. fuel consumption was stated on the basis of the work performed, i.e. on the gross ton-miles worked and expressed as lb. of fuel per 1,000 gross ton-miles. Great Britain was one of the few countries where this vital statistical unit was not officially recognised. Apart from its use in measuring loco. fuel consumption, the gross ton-mile statistic was absolutely necessary for the preparation of any main line electrification scheme to determine the traffic load on the lines to be electrified. The writer expressed the view that the extra compilation costs would be more than balanced by the savings that would result from the use of this statistical unit for fuel consumption purposes and as a measure of railway operating work.

Mr. Strauss raised the question of the effect of oil-fired locomotives on the health of the staff working them. Experience on Persian, Rumanian and certain South American Railways that burn fuel oil showed that the persistent smell of the burning oil might affect the health of the engine crews working oil-fired engines for lengthy periods. According to the technical press, well over 1,000 locomotives of the British railways were being converted from coal to oil burning ; it was hoped that the authorities concerned would collect all the information on experience with oil-burning steam locomotives from foreign railways who had a good knowledge of all the problems connected with this type of loco. fuel. The National Union of Railwaymen were considering the preparation of a memorandum on this subject for submission to the Ministries concerned.

Mr. J. I. Hill wrote calling attention to the need for a study of the chemistry of combustion of low-grade (high-ash) fuels in the locomotive firebox, similar to the investigations already made upon coals of good quality. British locomotives were designed for high-grade fuels and, although some Scottish coals were of rather poorer quality than others, prior to 1939 high-grade coals only were used. The best hard steam coals contained only some 4 per cent. ash, nearly all inherent and with practically no adventitious clay, shale or pyrites. Typical good coals would have a C.V. (on air-dried coal) of 15,000 B.Th.U./lb. One speaker had stated that the average C.V. of loco. coal was today 12,000 B.Th.U./lb. ; assuming that this was determined by British Standard methods, this would indicate an average ash content of nearly 20 per cent. above that contained in pre-war coals. Such a high proportion of non-combustible matter, in addition to reducing the amount of heat available from the coal, might have far-reaching secondary effects in retarding the free flow of primary air through the fire by accumulation of ash and formation of clinker. This in turn might cause the formation of CO instead of CO_2 and therefore a lower temperature of the flue gases leaving the firebox, leading to less steam production and lower boiler pressure ; since the draught depended on the exhaust pressure, the quantity of primary air would be again reduced thus leading to progressive deterioration of the conditions until the train had to be stopped to clean the fire.

Experimental support for this view was contained in a paper by the then chief chemist to the L.M.S. railway (P. Lewis-Dale, J.Inst.F., X, 68) in 1936. Practical trials showed that the average loss of heat, due to formation of carbon monoxide, whilst running under good conditions with good coal, ranged from only 0·4 per cent. to 1 per cent. of the total heat available ; but in another test he showed that for a period of 40 minutes, when the engine was working with a bad fire, due, he stated, to a little bad coal, the loss, due to the formation of carbon monoxide, was 9 per cent. of the total heat available ; what it could be when the coal was wholly bad had not been determined, but it must be high and to determine this would be an interesting extension to Dr. Dale's investigations. Low-grade fuels could be used on stationary boilers by increasing the draught. This measure was not possible on locomotive boilers and therefore the railways should be supplied with high-grade coal only.

THE CHAIRMAN, **Mr. V. M. Barrington-Ward,** summing up the discussion, said that the average age of engines on the L.N.E.R. was 33 years, and the company was quite prepared to have new ones if it could get them. Exports were important ; but there were contractors building locomotives which were being paid for by the British Government, he believed, and sent to the Continent, while locomotives on the Continent were being sent back here for repair. He suggested that the contractors should produce locomotives for the British railways, and that the British locomotives on the Continent should be repaired by fitters in the Continental countries.

3. The Space Heating of Passenger Stations

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Railways are doing much to improve the methods adopted for heating and ventilation in their premises. One railway recently built an entirely new station of a design based on the unit principle with the idea of standardised application. This embodied, among other features, a low-temperature radiant panel-heating apparatus run by hot water circulation from a thermostatically controlled gas-fired boiler. It is not suggested that this particular system will necessarily be widely adopted—it depends on the price charged for the supply of gas and whether or not there is difficulty in handling solid fuel. The installation is, however, referred to as indicating the readiness of the railways to experiment with new methods.

A modern station embodies a good deal of change in its structure as compared with its prototype, and there are signs that the architect's design and selection of materials has been influenced by the heating engineer with his desire to conserve heat input by the use of materials, both structural and decorative, having low co-efficients of heat transmission.

Requirements

The space-heating requirements for a passenger station must be considered in relation to those for hot water supply and frequently for cooking also, besides many other variable factors, which do not permit the adoption of any universal standards. Some of the factors are as follows :—

(1) The determination of " comfort conditions " for passengers and staff, bearing in mind the impossibility of suiting all tastes in public rooms.

(2) The varying period of user for different premises on a station and the extent to which some local control of internal temperatures and air change is necessary.

(3) The balance of other heat loads for hot water supply, cooking, etc., so that all services may be efficiently combined.

(4) The need for robust, foolproof apparatus in the public rooms.

(5) The need for plant which is not only thermally efficient but simple to operate and maintain, preferably with labour recruited from the ordinary station staff.

(1) COMFORT CONDITIONS

Comfort is a relative state ; the determination of temperature and humidity to suit the vast numbers of people using station public rooms is therefore a well-nigh impossible ideal, particularly when these people are wearing clothing for external climatic conditions, which in this country of ours are often subject to rapid change from hour to hour ! Nevertheless, it is possible to create with reasonable efficiency a comfortable atmosphere for the majority by the careful employment of modern radiant-heating apparatus with thermostatic control.

Very comfortable conditions have been obtained by the provision of a low background temperature of, say, 50° F.–54° F., designed to offset the " body " radiation loss to cold walls, supplemented by additional radiant heat, preferably from a high-temperature source. Whilst the resultant dry bulb reading may not exceed 58° F.–60° F., the globe thermometer or equivalent eupatheoscope reading, is, of course, several degrees higher. If this is coupled with an air circulation of, say, $2\frac{1}{2}$ ft.–3 ft. per second and a wet bulb reading of, say, 52° F., the resultant effect is something approaching comfort. It is not, of course, necessary in the normal-sized station to consider humidity control, but much can be accomplished with correct effective temperature and air movement, and what has been said indicates the ideal to be aimed at.

(2) VARIATION IN USER

Passenger stations usually embody accommodation for the various local administrative staffs, various departmental maintenance staffs, storage, passimeter, parcels, mess rooms and other miscellaneous accommodation, in addition to the public waiting and refreshment rooms, cloakrooms and lavatories, etc. Some of this accommodation has an intermittent user, whilst other portions are occupied 18–24 hours per day, seven days per week.

As it would be uneconomic to maintain rooms at relatively high temperatures during long periods of non-occupancy, special arrangements should be made for the occupants to have at least the greater proportion of heat requirement under their control, which for rapid heating should preferably be from a high-temperature source.

(3) HEAT LOADS OTHER THAN SPACE HEATING

Hot water and cooking facilities must be provided. During the summer it may be found economic to supply the domestic hot water demand by a smaller unit, or by a different heating medium.

(4) NEED FOR ROBUST APPARATUS

In public rooms, heating apparatus should be not only robust, but inconspicuous and easy to clean. Even under the best conditions, considerable damage often results from undue interference by the travelling public. Equipment on a station should be as nearly as possible foolproof—in fact one may say " hooligan-proof ".

(5) SIMPLICITY OF OPERATION

Labour for hand stoking of boilers is usually available at most stations, and, because this is a part-time charge, the costs are relatively low. The use of comparatively inexperienced grades accentuates a necessity for simplicity in operation and the avoidance of accessories the adjustment of which might be beyond the skill of these grades. The railway companies have, however, facilities for training, and instruction in efficient stoking is given both to full-time and part-time firemen.

Railway station premises were in the main designed many years ago during the years of fuel plenty when the open firegrate and the stove were considered the normal means of heating. The replacement of old apparatus with modern equipment therefore represents a task of some magnitude, but this is gradually being undertaken and considerable improvement has already been achieved, not only in new but also in existing stations. Naturally attention has been given first to old-fashioned and wasteful fireplaces which have mostly been replaced by more modern grates and many of these, if carefully tended by the staff, give reasonably efficient heating. Modern open fires designed to burn coke and fitted with gas ignition are destined to prove very useful for isolated premises, where no centralised system could be justified.

Methods of Heating

The broad types of heating systems which are in frequent use may be listed as follows :—

(*a*) Low-pressure hot-water systems (gravity and accelerated, with convector radiators, radiant panels, and even, in special cases, by means of floor heating).

(*b*) Low-pressure steam-heating systems.

(*c*) Direct electric-heating apparatus (tubular heaters, radiators, etc.).

(*d*) Direct gas-heating apparatus (fires, radiators, radiant panels, etc.).

(*e*) Combination solid-fuel grates and stoves (anthracite, coke, etc.).

The justification for adopting central heating in a given case is largely dependent upon the heat load, and also the local cost and availability of coal, coke, electricity, oil and gas. In many instances it is found that a low-pressure hot-water-heating system gives the most economic results besides being simple to operate and maintain. However, it is often necessary to adopt forced circulation in order to overcome the difficulty of laying return mains across the tracks and to avoid fixing the boiler at the awkwardly low level necessary for gravity circulation. Low-pressure steam is usually only justified if steam is required for some purpose other than space heating.

For the station with a relatively small load, direct-fired apparatus, either solid fuel, gas or electric, particularly with thermostatic control, is often effective and efficient, besides having a relatively low capital expenditure.

The domestic hot water and cooking load sometimes leads to the use of a combination stove in order to secure the maximum efficiency.

An important aspect in the design of a station heating system is its capacity for extension and modification, owing to change in the nature of the use of the accommodation. This requirement of adaptability in the station installation should also take into account the possibility of future development and of adjacent railway premises that may grow up and demand consideration.

The selection of the most suitable fuel is not always dependent purely upon cost, as it will be appreciated that availability, storage and continuity of supply all have their influence.

Water systems employing thermal storage, using off-peak electricity, are not generally acceptable at present for railway stations owing to relatively high operating costs, but the inherent advantages of this system are appreciated, and should the balance between fuel costs continue to change it will merit further consideration.

Special Problems

Before concluding these remarks it is proposed to make brief reference to some of the special problems which occasionally arise in railway station heating.

(1) PASSIMETER BOOKING OFFICE

This has been designed specially to control booking at isolated entrances and is by its nature detached from the main building. It is usually confined in space, probably has no opportunity of a natural flue outlet and is almost invariably in a draughty position. In such cases electric or gas heating is often the best solution and can be effected by tubular heaters neatly packed away so as not to restrict the already cramped conditions. These heaters will give the background heating and may be supplemented by gas or electric radiant heaters where necessary to relieve the discomfort that would otherwise arise from the draughty window openings.

(2) AN OPEN PARCELS OFFICE WITH LOADING DOCK ON ONE SIDE AND OPEN ACCESS TO THE PLATFORM ON THE OTHER SIDE

This is a type of office by no means uncommon and although the openings on either side of the office are doubtless provided with roller shutters or other means of closure, the operation of the office demands that the doors shall often remain open for a considerable length of time and in cold weather the staff are exposed to very draughty conditions. High surface temperature radiant heaters near ceiling level have been found to prove most effective in warming the occupants in premises of this character. However, it would appear that there is ample scope for the gas and electrical industries to produce more efficient apparatus for application in buildings of this nature.

(3) TICKET COLLECTORS' HUTS

Ticket collectors always have a very unenviable task in cold weather and it has always been recognised that they should have as much protection as possible by means of small huts, often similar to a sentry box. Of recent years there has been increasing demand for the warming of these huts, and this is another case where radiant heating appears to be the most effective solution. Side panels of shallow design have been found most satisfactory. These can be heated electrically where current is available, but radiant panels with internal gas burners have also been found to work satisfactorily. However, owing to the confined space, low-source temperatures are necessary, and where the structure is permanent, floor and wall panels would produce maximum comfort for the occupant. From the point of view of fuel economy, a very important addition to the equipment of the collector's hut should be the provision of a door to the lower half of the hut, so that under the worst conditions the collector can stand inside the hut and collect tickets through the open top half with some possibility of keeping his feet warm.

In conclusion, it may be pointed out that the railways, although primarily a public service, are at the same time a commercial undertaking, so that plant capital expenditure and annual operating costs have to be carefully considered for each installation. Specialist staff are constantly in touch with all modern development and research. There is exchange of information between the main line companies and L.P.T.B. through various Inter-Railway Committees and sometimes the research work gains more widespread circulation through the professional institutions.

4. The Space Heating of Hotels and Offices

By E. MORGAN, B.SC.

LIGHTING AND HEATING ASSISTANT TO CHIEF CIVIL ENGINEER, L.M.S. RAILWAY COMPANY

The British railways are amongst the largest owners of property in the country. Their buildings range from large blocks of offices housing upwards of 1,000 people to the small village goods office, which may often be an isolated room. They also own hotels. Every style of architecture over the last half-century is represented, from the massive Victorian building with its two-foot stone walls to the lightest of wooden structures. Many of these buildings were erected in the second half of the last century when coal and labour were plentiful and cheap. There was no incentive to instal other than the most easily maintained form of heater, the obvious method being the open fire or the cast-iron stove.

ORGANISATION

The heating problem of railway hotels and offices is twofold, the installation of new schemes and the efficient running of existing installations.

In the course of the development and modernisation of their premises, which must follow good management, there is a steady flow of new building projects. This flow is being intensified as a result of the war, which interrupted the ordinary building programme and which brought in its train the damage or destruction of many of their buildings. Secondly, even when no building work is involved, there is a considerable volume of periodic renewal of plant which has served its useful life. Lastly, and probably the most important of all from a fuel saving point of view, is the replacement of out-of-date inefficient plant by modern highly-efficient plant.

The efficient running of existing installations begins with the stoker. Stoking involves quite a degree of skill and all stokers should be adequately trained. The stoker should be supplied with the correct tools, and he should be encouraged to look after them and be able to get renewals when required.

Second in importance to the stoker is the maintenance fitter. His duties, which, of course, include routine overhauls and adjustments and the making good of defects, should be scheduled and care should be taken to see that the schedule is carried out to time and not, as is so often the case, when there is no other work to do.

Lastly, a fuel efficiency organisation is worthy of consideration. On the railways such organisations exist, which by suitable publicity and the employment of Fuel Efficiency Officers to check abuse and advise the user, have done a good deal to save fuel. It should always be remembered that fuel saved is not only in the national interest, but is also money saved.

The organisation of the railways to deal with these two phases of heating varies between the individual companies, but broadly speaking, new building work is designed and installed from headquarters and maintenance is carried out by District Engineering Officers. This enables the employment of qualified heating engineers at headquarters, who, whilst their prime job is to design and supervise the installation of new heating schemes, can also advise on unusual maintenance problems. It also enables the artisans who carry out the maintenance work to be stationed at convenient points throughout the country within easy access of their plant.

A further advantage of locating the heating engineers at headquarters is that they are in easy touch with the architect who designs the buildings. It is now generally realised that heating is not a necessary evil but is a vital feature of any building and that consultation between the architect and the heating engineer at the earliest possible stage of design is essential. This avoids much alteration of plans and duplication of effort.

DESIGN CONSIDERATION

The amount of heat required by a building is governed by well-known factors, which do not need to be discussed here. Suffice it to say that if the annual fuel consumption is to be kept to a minimum, two essential features are that the heat losses of the building should be kept to the lowest practicable level and that the apparatus which converts the energy of the coal into usable heat should have the highest practicable efficiency. The word " practicable " is used because other factors such as cost and convenience require consideration.

The traditional materials such as bricks, stone and concrete are relatively poor insulators. Much thought and research has been devoted to alternative materials for new buildings, which, whilst possessing the virtues of the traditional materials from a structural point of view, will give lower thermal conductivities. Many of these materials have been described in the literature, but one railway company has under development and test a novel type of unit construction which may not be familiar (c.f. W. H. Hamlyn, The Builder, 8th February, 1946).

The outside surface is formed by a series of rectangular enamelled-iron dishes each 3 ft. 4 in. by 1 ft. 10 in. by 4 in. deep. The inside surface is formed by sheet material such as plywood or insulating board, thus enclosing a 4-in. air space which, if required, could be filled with fibrous insulating material. The inner and outer shells are secured in position by clips to a light steel framework. The joints between the enamelled iron dishes are filled with a suitable mastic. Because of its unit principle of design the whole assembly can be prefabricated to permit of rapid erection on the site.

With this type of construction it is possible to achieve an overall conductivity of 0·21 B.Th.U/sq. ft./° F./hr. with a weight per square foot of surface of only 12 lb. as compared with 96 lb. for the traditional materials, which permits a considerable saving in the amount of structural steel. A conductivity figure of this order should be regarded as a practical value which could be attained at a reasonable cost.

The choice of the prime source of heat is largely governed by the manner of occupation of the building. There is no doubt that for continuous occupation central heating is the most efficient in fuel, but for short period occupation a radiant source of heat such as an electric or gas fire is worthy of consideration, particularly to " top up " in a room occupied by only one or two people. The system of providing background heat for such rooms from a central plant to give a temperature of 55° F. under extreme outside conditions with enough bright radiation to top up to 65° F. is very attractive. It has the advantage that for a large part of the heating season no " topping up " is required, but it is available for night use outside the heating season when the central plant would normally be out of commission. It also finds a useful application in private rooms in hotels, which may be required at short notice. It is not readily applicable to public rooms and large general offices owing to the difficulty of siting the radiators, nor would it save fuel as these rooms are normally continuously occupied.

SYSTEMS OF HEATING

The principal systems of heating commonly in use in railway offices and hotels are :—

(1) Ordinary central heating.
(2) Plenum heating.
(3) Direct heating by individual sources such as solid fuel fires or stoves, gas appliances and electrical appliances.

Individual appliances find their main use for small buildings or isolated rooms where the higher installation cost of central heating is not warranted.

For most offices and hotels, apart from special rooms, the question of ventilation is largely a matter of refinement. If dirt and noise are to be excluded, it is essential to keep the windows closed and a plenum system providing warm filtered air is required. We have found that when a plenum system is used it is necessary to increase considerably the summer ventilation rate as compared with the winter rate, and this normally is achieved by altering the fan pulleys.

FUEL

In deciding what fuel to use our main consideration is the total annual cost which includes in addition to the cost of fuel, the stoking and maintenance of the plant and the interest charges. Thus, although solid fuel has an initial advantage, it has been found more economical in several recent central-heating schemes to use oil or gas. With rising costs of labour and coal, it is probable that in the future there will be an extended use of these more refined fuels.

FUTURE DEVELOPMENTS

Whilst the science of heating has made considerable strides in recent times, there is still scope for a good deal of research and experiment. On the railways all heating plant that is installed is studied from a performance and efficiency point of view. Among the problems which have engaged our attention and on which we are still unsatisfied, are dust filtration and thermostatic control.

The removal of dust is a subject which is becoming more important as consideration is given to the erection of important buildings in very dirty locations, and so far we have not come across any filter which is sufficiently effective. Many commercial filters are quite effective against the coarser particles, but the fines, which damage the internal decorations, still defy all our efforts. It is therefore suggested that systematic study of these fine particles may prove profitable.

The problem in thermostatic control is to relate the operating element to the room temperature which it is intended should be controlled. We have found by tests how difficult it is to select a truly representative position for the temperature-sensitive element, particularly in large offices and public rooms. It is again suggested that this subject may profitably be studied.

Finally, I would like to propound a paradox. " Has electrical thermal storage been tried without storage water ? " Electrical thermal storage usually implies heating water electrically, outside the peak, so as to secure the most favourable rate, and storing it for circulation later through a system of radiators. If power station conditions were favourable, it might be possible to use the thermal capacity of the building itself as a heat store. For example, with a morning peak between 8 a.m. and 10 a.m., it might well be possible by preheating before 8 a.m. to store sufficient heat to last until 10 a.m., when " off-peak " heating could be resumed.

Whilst the railways are fully alive to the possibilities of conserving fuel by the employment of up-to-date methods of heating, due consideration must always be given to the financial results of expenditure.

Discussion

Following the presentation of these papers there was a short general discussion in which the following took part : Messrs. **Telpher, Hunt, Harrison, C. B. Cleland** and **K. C. Kerry.** Among the points made were that the best results could be achieved by controlled heating, that correct architectural design could save more fuel than the combined efforts of heating and ventilating engineers, that more information was needed on the running costs of different heating plants, that gas and electrical heating were more convenient and required less space than solid fuel, the value of low-temperature heating panels for halls, passages, etc., and the possibilities of the heat pump. **The Chairman,** summing up this part of the session, pointed out that there was now a general demand for more comfort and that the better working conditions were leading to less sickness and less absenteeism. " A warm staff is a happy staff ".

SECTION F.

SPECIAL INDUSTRIAL SESSIONS—*continued*

SESSION III. The Coal Industry

Chairman of Session: PROF. A. M. BRYAN, B.SC., F.R.S.E.
CHAIRMAN OF THE COAL INDUSTRY JOINT FUEL EFFICIENCY COMMITTEE

THE CHAIRMAN summarised the steps that had been taken to promote fuel economy at collieries. In addition to its supreme duty of providing adequate supplies of coal, the coalmining industry had endeavoured (*a*) to secure the maximum efficiency in the generation, transmission and use of energy in every form, (*b*) to use at the collieries the minimum quantities of those grades of fuel which were in short supply, and (*c*) to operate cleaning plants with the maximum efficiency. To promote these objects, the Mining Association of Great Britain, in conjunction with the Fuel Efficiency Committee of the Ministry of Fuel and Power, set up the Coal Industry Joint Fuel Efficiency Committee. This committee set out to investigate the way in which each of the objects set out above could be best achieved. District committees were immediately set up and panels of visiting engineers formed to visit collieries to make inspections and to give advice and guidance when required. Two technical panels were set up, one to report upon the application of low-grade fuels produced at collieries or coke ovens to steam raising and the other to report upon coal cleaning, including the re-treatment of old tips. The Chairman expressed the hope that the National Coal Board would ensure that this work was continued.

Collieries had always used for steam raising coals that the industrial consumer would not normally accept ; for this reason the tonnage of boiler coal used at collieries might appear high in relation to output and it had been impossible for many collieries to show any remarkable savings in marketable qualities of coals in short supply. Nevertheless, the work of this committee had enabled some collieries to save fully 12½ per cent. on the tonnage of these qualities of coal by making greater use of low-grade material which would otherwise have been dumped. Modern coal preparation results in a concentration of low-grade material which when discarded causes considerable waste of material. Although the total fuel value of these discards might not be large by comparison with the washed smalls and lump coal, these provided an important fuel reserve against emergency and might have to be used to bridge the gap between production and consumption.

With advances in mechanisation, power production and utilisation at collieries was becoming more and more important. As already indicated, steam raising was becoming increasingly influenced by coal preparation practice, and colliery boiler fuel was the more or less unmarketable product of the coal cleaning plant. Modern methods might enable much waste to be avoided at washeries. The supply of electricity, whether from colliery plant or from public supply, gave great scope for thought and discussion. The use of compressed air was necessary at various pits because of the risk of underground ignition, but added considerably to the demand for steam, and it must therefore be used to the best advantage. Underground pumping formed a great part of the power load at many collieries. In all these fields of fuel efficiency at collieries there was still great scope for improvement and progress, and papers would be presented dealing with them. With the collieries hard pressed to maintain production, every little economy that could be effected in the production and use of coal would assist in bridging the gap between production and demand.

1. Utilisation of Low-Grade Fuels at Collieries—The Work of Panel I

By R. G. EVANS

CHAIRMAN OF TECHNICAL PANEL NO. I

The terms of reference of the panel were :—

> " To study and report on the problem of the application of low-grade fuels produced in coal preparation for the market (including also coke breeze produced in preparation of coke at coke-oven plants) to steam raising, dealing mainly with the performance and suitability of the various types of boilers, furnace grates and auxiliary equipment now available, combustion problems, handling and feeding of the fuel, moisture and ash limitations, fly ash and grit, and labour conditions."

The panel early came to the conclusion that the ability of collieries to utilise their unmarketable fuel depended, *inter alia*, on (*a*) their installed boiler capacity relative to the demand for steam, (*b*) the type of furnace fitted to the boilers and whether specially designed to utilise a particular class of unmarketable fuel, and (*c*) the varying nature of the colliery power load.

The rapid extension of mechanisation in recent years has reduced the ability of some collieries to extend, and even maintain, the use of slurry and other low-grade fuels at present levels, whilst the prospective life of many collieries may preclude the adoption of the plant required for the efficient utilisation of the low-grade fuel available. Nevertheless, while much of this low-grade fuel is inferior in quality, its evacuation to the spoil banks or accumulation in settling grounds cannot be justified under present conditions except under special circumstances. Experience shows that it can be used for steam-raising alone when the boiler capacity and type of furnace are suitable, or when blended with other fuel. Special furnaces and equipment are necessary for the successful utilisation of such low-grade fuel. Wherever possible the principle should be to upgrade it so that it can be sold in normal markets, and only to use it in low-grade form as a last resort.

Not all collieries have been able to follow the lead given by the committee. Among the various factors influencing this are :—

(1) The low-grade fuel formerly used as such is now upgraded, both for colliery boiler consumption and the market.

(2) The supply of unmarketable fuel has become insufficient to meet the colliery steam requirements.

(3) Difficulties with labour have rendered it necessary to use higher grade fuels, either alone, or blended with low-grade materials. The trend appears to be for collieries which successfully maintained their steam load before and throughout the war period on slurry or a similar grade of fuel to be compelled to use marketable washed slack, and in some instances,

still better grades. This results in the unwanted slurry being run into settling grounds from which it is feared that recovery—in some instances—will not be easy.

Attention should be drawn to the insistence with which certain aspects of the problem are mentioned in the reports of Panel I :—

(*a*) The need for blending low-grade with other fuels in order to supply the boilers, not with high-grade or saleable material, but mixtures of as constant a size and quality as is possible to produce under day-to-day colliery conditions, making the fullest use of all usable low-grade material.

Members of the panel feel that a good case exists for consideration of the advantages to be gained from the establishment of central blending and upgrading plants in conjunction with central power stations in each area where conditions and supplies of suitable fuel justify such a step. Such plant would also provide, with minimum labour, the power required for the operation of colliery power plants at an appreciably lower cost and economy in fuel than is possible under present conditions.

(*b*) The urgent need for a suitably designed mechanical stoker for use with Lancashire boilers for firing low-grade fuels and blends. This should include not only a means of feeding the fuel into the furnace, but the delivery of the resulting ashes into the ashpit and thence to the ash conveyor.

There are good grounds for the belief that the successful development of such equipment would be of considerable assistance in ensuring the maximum use of the low-grade fuels that are available, and the consequent release for the market of the saleable fuel that is now consumed in the colliery boilers. Members of the panel have frequently been impressed by the high labour requirements of hand-fired Lancashire boilers when using low-grade fuels, whereas they have observed that these difficulties do not arise with water-tube boilers.

The panel concluded in its second report that unless the fuel was reasonably low in ash and moisture, no good case could be formulated for pulverised-fuel firing, especially in Lancashire boilers. Further information derived from the examination of additional steam-raising plants has enabled this statement to be amplified in the third report. From the examination of seven plants referred to in that report the conclusion is reached that fuel of moderately high ash content can be used for pulverised-fuel firing of boilers, providing certain precautions are taken in the design of the plant and its operation. It is, however, emphasised that plants using good quality fuel give the best results, this statement being related to the fusibility of the ash.

There still remains considerable ground to be covered in areas where conditions are different from those which have, so far, been studied by the panel. This applies particularly to the anthracite field where it is understood that much useful work has been done in connection with the efficient utilisation of fines and slurries for steam raising and also to the conditions of steam raising and the results obtained at large undertakings where central power stations are in operation.

The panel also has in view the preparation of detailed descriptions of the furnaces and grates which have obtained a confirmed good report in the burning of low-grade fuels, together with follow-up visits to new types of mechanical stokers for Lancashire boilers.

2. Coal Cleaning—The Work of Panel II

By Dr. J. H. JONES

The author gave an account of work carried out at Northumberland and Durham collieries which had resulted in saving appreciable quantities of coal, and suggested that similar work might be undertaken in other regions.

Some information as to the amount of coal which it was possible to recover had already been gained in the coalfield in connection with the Ministry of Supply scheme for the recovery of pyrites from colliery refuse. In 1943 five pyrites plants, treating colliery refuse, were operating in the region. The refuse was crushed and subjected to density separation, using plant similar to that employed for coal cleaning. During the crushing necessary to free the pyrites a significant amount of coal was liberated and it was known that such plants, operating with a throughput of 10–20 tons/hr. could recover more than 100 tons of coal a week as a by-product. The raw material for the plants was chosen for pyrites content rather than coal content, in view of which it seemed certain that appreciable quantities of coal were being discarded with the refuse at many of the local collieries.

In carrying out the investigations for Panel II, one of the first difficulties encountered was the length of time it was necessary to spend at a colliery if reliable figures were to be obtained. Belt refuse, in particular, was difficult to sample, being variable in quality and quantity, and it was, therefore, stipulated that any test should cover a minimum period of six hours. Washery refuse presented fewer difficulties but here again, owing to variations in input, snap tests were useless. At some collieries, where adequate chemical staffs were available, the work was facilitated by the fact that the refuse had been sampled daily, so that the figures for as many as 250 separate determinations were available in each year, thus allowing the true position to be assessed. At other undertakings, the chemical work was restricted to three or four tests a year and in such cases the available figures were of much less value. Any occasional test, however carefully conducted, suffered from the disadvantage that the men both at the belts and the cleaning plant, knowing that a test is in progress, deviated from their normal course of procedure.

Some of the cleaning plants in Northumberland and Durham were designed to treat raw coal which was much cleaner than is now produced and they were failing to give a satisfactory performance under present conditions. Under such circumstances, if the plant were adjusted so that the dirtier input still yielded a clean product for sale, then coal was lost in the refuse and, on the other hand, if the refuse was maintained free from coal, then the vendable coal might be too dirty. The poorer input also often contained much larger quantities of middlings which could not be efficiently treated in the older type of plant. Coal losses could often be reduced by crushing and re-treating the refuse but to crush material of low coal content was an expensive procedure which must be balanced against coal recovery and the general efficiency of the plant.

Dr. Jones estimated that the combined efforts of the panel and the pyrites programme had resulted in a saving considerably in excess of 60,000 tons of coal a year. He went on to mention some of the most interesting cases that had been studied.

(1) At a colliery in South Durham the fines refuse from a Baum washery was re-treated on two concentrating tables with a consequent recovery of 50 tons/week of coal of sufficiently good quality to be incorporated in the coking slack.

(2) At a coke works in North-West Durham an old dry-cleaner was discharging refuse containing over 10 per cent. of coal. This could not be rectified without affecting the quality of the cleaned coal which was required for carbonisation. The firm in question was experimenting with heavy-density washing and a small density washer, of 10 tons/hr. capacity, was designed to treat the dry-cleaner refuse. The results obtained were most satisfactory and the combined plant remained in operation until it was superseded by a modern density washer, of which the small 10 tons/hr. installation formed the pilot plant.

(3) Considerable information was obtained by transporting refuse, from an undertaking in East Durham using dry-cleaners, and re-treating it in a modern heavy-density plant in West Durham. Unfortunately, although the coal recovery was substantial it could not justify the transport of refuse from the east to the west of the coalfield.

(4) An operation of the same type was, however, carried out by one member of the panel who discovered that it was economically sound for him to take refuse from an old jig washer at a neighbouring colliery and re-treat it in a modern washery, thereby recovering about 3,500 tons of coal a year.

(5) At a colliery in Northumberland where a jig washery was not fully employed, the chemist, a member of the panel, introduced a crusher and modified the operation of the plant to enable him to re-treat, at a substantial profit, a heap of 40,000 tons of refuse, produced by an earlier washery.

(6) At a colliery in East Durham the cleaning plants, both jig and dry-cleaner, were old and inefficient. It was estimated that, in all, about 14,000 tons of coal were being lost annually in the refuse. This figure, which was a Coal Survey estimate obtained in the course of a pyrites survey, related to coal recovery after crushing to pass ⅜-in. and was larger than could be expected in practice. The company repaired an old washery, erected in 1890, and utilised it to treat the refuse. The amount of coal recovered was stated to be about 10,000 tons/annum and the plant was still in operation.

Apart from the substantial recovery of coal at individual collieries, the most important effect of the work had been to bring to the notice of the officials concerned the point that apparently insignificant losses amount to a considerable total when allowed to persist.

In conclusion, the author mentioned three points which the panel considered to require emphasis :—

(1) Run-of-mine coal has deteriorated so that effective cleaning has become more difficult, with increased loss of coal in the refuse.

(2) In the past much of the coal rejected during cleaning was due to economic conditions which forced the collieries to prepare grades of coal with an insufficient margin between the inherent ash and the ash of the vended product. It is suggested that the chemist, rather than the sales

organisation or the consumer, should fix the ash contents of the vended products and that this should only be done after a careful study of the washability characteristics of the coal which forms the raw material. The balance between the vended products should be so adjusted as to give the maximum over-all efficiency ; any other procedure merely results in the loss of coal, whatever may be the temporary financial advantages thus gained.

(3) Much advantage would be derived from the adoption of a definite policy with regard to the treatment of middlings. In the older types of plant, middlings are either lost with the discard or alternatively allowed to degrade the vended coal. In some instances, arrangements for the separation and marketing of the middlings have simplified washing and decreased coal losses and, at the same time, provided a fuel acceptable to certain types of boiler plant.

3. Power Generation at Collieries from Low-Grade Fuels

By A. B. MUIRHEAD, M.I.MIN.E., M.I.E.E., A.M.E.M.E., M.INST.F.

This contribution will discuss the conditions which apply to the steam and power demand at collieries and the steps which may be taken for the increased use of low-grade fuels for steam raising to meet these demands.

To understand the complex nature of the problem it is necessary to know something of the factors that enter into and materially affect the steam and power demand in coal mining operations. The conditions vary, not only in the different areas in each mining district in Great Britain, but at individual collieries in each area, with the result that standardisation of power generating plant is not practicable. Apart from mining conditions such as depth of shaft, inclination of workings, and output to be raised per winding shift, all of which have a direct bearing on the size of the plant and the steam and power demand to meet it, there is considerable variation in the plant required and in the power demand for a variety of purposes such as ventilation, main pumping from the shaft bottom, in-bye pumping, haulage, coal-cutting and conveying, and for the coal preparation plant at the surface. It is often necessary in the interests of safety to use compressed air for the operation of underground plant. This adds considerably to the steam demand compared with that of collieries which are in the more favoured position of being able to operate all their underground plant electrically. It is interesting to note that during recent visits to certain colliery groups where the steam demand for ventilation and for compressed air is high, the panel was informed that the reduction in output of coal experienced in recent years had not been accompanied by a material reduction in the steam demand.

The colliery power load varies within wide limits. Colliery boiler and power plants have to contend with the most difficult load in any industry. In normal practice the main winding and haulage duty is responsible for the maximum load demand on the day shift, or on both day and back shift of each working day, as the case may be. Ventilating and pumping—in many collieries a heavy demand—is a continuous load. Coal-cutting operations—either with electricity or compressed air—are usually carried out during the night shift.

In recent years electrically-operated coal cutting combined with mechanical loading machines have been introduced in a limited number of mines. This development, if found practicable in wider application, will increase the demand for electrical power during the winding period.

It follows from the nature of the load that the steam and power plant has to be kept in service night and day and during week-ends and holiday periods to meet the plant requirements.

Brief reference will now be made to the history of power plant development to meet the colliery load.

It has been the practice in the industry to make use of new types of plant and appliances designed to improve the efficiency of steam-raising and to minimise the fuel demand for the production of power. The pace set in these directions has, as a rule, been governed by the designers and manufacturers of such plant rather than by the personnel responsible for the conduct of the mining industry. The introduction of the mixed pressure steam turbine made it possible to use the exhaust steam from the main winding and other engines during the winding shift for the generation of electrical power and compressed air.

During the afternoon and night shifts, or out with the winding period, the load has to be met from live steam taken direct from the boilers; this may be supplemented by steam from the main ventilating fan or other engines which require to be kept in constant service, and this explains to some extent why the mining industry is responsible for the consumption of some 12,000,000 tons of fuel per year. Low-grade fuel has long been used to meet this consumption to a greater extent than is generally appreciated. If statistical reports relating to the distribution of coal, and which give the total consumption at collieries, stated this in percentage of marketable output and percentage of unmarketable output in each district, the information would be of considerable use to all who are interested in the problem of fuel saving.

Consideration will now be given to the steps which should be taken to increase the use of low-grade fuels to meet the requirements of the mining industry. Mr. Evans has referred to the case for central blending and upgrading plant in conjunction with central power stations. Central power stations for the generation of power for all the various collieries in the group have been introduced with conspicuous success in several areas in the British coalfields.

A stage has been reached when a more comprehensive review of the utilisation of low-grade fuels should be made in the light of the increased demand for power at collieries. The steps which are being taken at the present time to merge the colliery undertakings in each area offer a favourable opportunity for consideration of this aspect of power supply. It is reasonable to forecast an increased demand for power for coal-cutting and loading plant, haulage and underground transport, which, together with new main winding plant, will be required at many collieries to meet the increased demand due to improved methods of working.

Smaller collieries where the boiler power is limited, often inefficient and inadequate to meet the requirements if the low-grade fuels are used, present a good case for complete electrification, provided always that the estimated life of the colliery justifies the step.

There is room for consideration of the pumping problem in some areas. It may be found that this can be dealt with much more economically at selected points, and with advantage to the mining operations in the area.

There is also the larger question of the provision to be made for the power demand for new sinkings.

The setting up of central power stations at suitable points in the respective areas will facilitate developments in each of these directions, and if central plants for blending and upgrading of low-grade and other normally unmarketable fuels are established in conjunction with central power stations, facilities will thus be provided whereby all grades of steam-raising fuels may be used to greater advantage and power for plant operation will be produced at the lowest possible working cost.

To revert once more to compressed air as an example : this form of power is costly unless it is generated from exhaust steam. It appears to be a mistake to perpetuate any system whereby it will be generated from marketable fuel or purchased from the supply companies at present-day prices, but there are good grounds for the expectation that the cost of electrical power generated—whether for general or " base " load purposes—in the low-grade fuel central stations will be sufficiently low to admit of either high-pressure steam turbo-compressors being run at the power stations, or of motor-driven compressors being established at the collieries, especially for service outwith the winding period.

The low-grade fuels to be dealt with at central blending plants seem to be a subject for the B.C.U.R.A. and their investigations should cover the use of so-called " refuse " coal. The blending process might provide means for dealing effectively with the utilisation of a considerable portion of the unwashed fines, thus helping materially in solving quite a number of problems in coal preparation and in the use of the lower-grade fuels at the source, incidentally creating a profitable outlet for them for steam raising in industries adjacent to the source.

The modern development in water-tube boiler practice whereby the chain grate is designed of sufficient area to burn the necessary fuel to meet the steam demand and is fitted with compartments for control of air admission, and with brick arches designed to promote ready ignition of the fuel, and with automatic ash-handling plant, enables the steam-raising part of the enterprise to meet all necessary requirements from a consistent grade and quantity of blended fuel.

Nor should it be forgotten that these central colliery power stations could be connected to the Grid for an exchange of power. This has been done to some extent in England with apparent advantage to both parties, and is receiving the further attention of the panel.

4. Colliery Power Problems—Fuel Economy by Complete Electrification

By N. S. WALKER

At many collieries today the only substantial items of steam-driven plant, apart, of course, from the generating plant, are the winders and the air compressors. Compressed air is, however, unsuitable for many of the mechanised mining schemes now projected and its use will probably decline. Compared with direct electric drive, the efficiency of compressed air operation is low. A ratio of three to one has been authoritatively mentioned and it is probably a conservative estimate.

Steam winders are also extravagant users of coal. It is not unusual to find that a steam winder consumes five times as much coal as would be used by a supply company to provide the energy requirements of the corresponding electric winder. Here are two examples and they are not exceptional :—

> Two winding engines were the only items of steam-driven plant at a colliery taking its electrical energy supplies from a power company's system. These winders required for their operation some 6,500 tons of boiler fuel a year and the consumption of the electric winders to replace them was estimated at 1,000,000 kWh a year. The colliery boiler fuel consisted mainly of washery settlings but the whole of it could be upgraded to a saleable condition with an over-all recovery of 60 per cent. Approximately 4,000 tons of saleable coal will be recovered whereas less than 800 tons will be consumed by the power company to supply the corresponding electrical energy requirements—a saving of 3,200 tons of coal. One of the new electric winders is now in commission and there is no reason to suppose that the electrical energy estimate for the two winders will be exceeded.
>
> At another colliery where only the winders were steam driven, 6,400 tons of coal a year were used at the colliery boilers. Less than 1,200 tons of coal are needed to supply the 1½ million units required for the operation of the electric winders which were installed in the place of the steam winders—a saving of 5,200 tons of coal per annum.

A more general arrangement is for the winding engine exhaust steam to be used for generating electrical energy in M.P. turbo-generators. Consideration of data available leads to the conclusion that in many instances it will be found that less than half the colliery boiler fuel in terms of saleable coal would be used by a power company to meet a completely electrified condition. All such cases should receive careful consideration particularly where Lancashire boilers are in use.

Where in addition to the winders there are scattered steam-driven units exhausting into M.P. turbines the coal saving to be effected by complete electrification may be still more substantial. For instance, a small group of collieries had two sets of generating plant with M.P. turbo-generators fed by low-pressure steam from the exhausts of three winding engines and other steam-driven units. A fourth coal winding engine exhausted to atmosphere. More than 36,000 tons of coal were burnt under the colliery boilers. Supplies were afforded from a power company's system and the colliery generating plants closed down. On completion of electrification (and only one small winder now remains on steam) the total energy consumption will be 11½ million kWh a year. To supply this energy a power company uses less than 9,000 tons of coal—a saving of 27,000 tons per annum.

In estimating the coal used by a power company to supply the electrical energy requirements a conversion figure of 1,300 kWh per ton of coal has been used.

This is derived from a schedule published by the Central Electricity Board which shows that at all the coal-fired stations operated under their direction an average of 1·42 lb. of coal were used for each kWh generated in 1944.

By making an allowance of 17½ per cent. to cover station auxiliaries, transmission losses, distribution losses and railway haulage from the mines to the power stations it may conservatively be deduced that for each ton of coal an average of 1,300 kWh is supplied to consumers.

This average is by no means representative of the performance of the larger power stations and it will improve as the supply authorities make up the leeway in their generator installation programmes, which were drastically cut down during the war. For the present, it provides a very conservative basis for the comparison of coal consumptions.

Complete electrification implies, of course, either the existence or the provision of coal preparation plant—probably including froth-flotation equipment—for the treatment of that portion of the colliery boiler fuel which would otherwise be unsaleable. Most low-grade fuels can be upgraded—there are exceptions, splint coal is one—but usually they present no great difficulty to the coal preparation expert.

For the close consideration and the preparation of a complete electrification scheme, collaboration between the colliery engineer, the coal preparation expert and the supply authority's engineer is desirable, preferably from inception of the scheme but, for the purpose of making a quick survey, the energy consumption of an electric winder may be taken at the rate of 2 kWh per ton per 1,000 ft. To the total consumption for coal winding it will usually be necessary to add 30 per cent. for the winding of other materials and men. Both, of course, are approximate figures.

There are many completely electrified collieries on the North-East Coast, where more than 80 per cent. of the electrical energy used at all the collieries is taken from the supply authorities' systems, and where more than half the winders are electrically operated. Among all those completely electrified collieries where compressed air is not in use, the highest individual consumption over a period of six months is 21 units a ton. This represents the use at a power station of 36 lb. of coal for each ton of coal produced at that colliery. The average consumption of all collieries in other parts of the country is approximately 150 lb. of coal a ton.

5. The Use of Compressed Air in Collieries

By J. A. METCALF, M.I.MECH.E., M.I.MIN.E., M.I.M.E.

The use of compressed air is wasteful and uneconomic as a medium of power transmission. Its use is often essential, however, and it is therefore the intention to bring out practical points from the compressor house on the surface to the coal face, which should have special attention, not only when installing a system, but maintaining it as economically as ever possible.

There are several excellent makes of compressors in use today, but unless care and attention is paid systematically, as prescribed by the makers, efficient performance of the compressor is bound to suffer.

POLICY

How often, when arrangements have been made to examine compressors the following week-end, some job crops up in the meantime in the pit which has to be done. What happens ? The compressor examination is put off until the next week-end and possibly the next. This is a penny-wise and pound-foolish policy !

With care, forward planning and organising of these " odd jobs " which crop up, at the expense of systematic examination of vital plant, can, in a well organised colliery, be effected.

Procrastination may result in the loss of anything up to 100 per cent. output daily, until repairs are carried out, the breakdown being the result, possibly, of some defect which could have been detected by a normal systematic examination.

COMPRESSORS

The dust-laden nature of the atmosphere, usually found around many present-day collieries, makes it necessary to fit suction air filters. These filters should be cleaned at regular intervals.

The following parts of the compressor should receive careful periodical inspection :—pistons, piston rings, connecting rod, big and little end brasses, cylinders, valves, etc.

Air ports and passages should be kept free from carbon deposit.

Water-jacket ports and passages should be kept clean to allow free passage of circulating water throughout the cooling system.

The intercooler (and aftercooler if in use) should be cleaned at regular intervals.

Care should be taken to record the water and air temperatures on completion for future guidance and comparative performance.

The lubrication of compressors should have special attention; any variation in the pressure indicated should be noted and immediately investigated.

One minute early in the detection of a fault is better than one second too late. A major repair may then be necessary.

Records of all examinations, defects, repairs and overhauls are invaluable to the present maintenance engineer and those who have to follow.

RECEIVERS

Care should be taken to discharge surplus water (condensate) and oil from the receiver.

Fusible plugs fitted with audible warning signals are advisable.

The safety valve should be checked for working pressure from time to time. The fitting of small receivers immediately behind in-bye auxiliary machines that are subject to intermittent use and varying loads is desirable.

PIPE JOISTS

The selection of pipe joists is of great importance.

There are pipes fitted today with varying types of self-sealing joints which are highly suitable for use with compressed air, on the surface, in mine shafts, and particularly in the in-bye workings.

The outstanding points of these pipes and joints are their flexibility at the joints up to 5°, simplicity of fitting (i.e. saving of time), and a reasonably long life of the rubber rings.

The flange joint cannot be compared with the self-sealing joint for compressed air as applied to mining.

This self-sealing type of joint is highly useful in shaft air ranges along with the use of expansion joints of similar design.

TRANSMISSION SYSTEM

Good and adequate supervision should be provided for the installation and maintenance of pipe ranges and particularly pipe fittings suitable for the various apparatus to which they are to be fitted.

Screwed pipes should be avoided at all costs: they are not reliable as regards leak-tightness under pit conditions.

PIPE-FITTINGS, CONNECTIONS

Special pipes with suitably welded branches should be used along with fittings and valves for hose connections.

The special fittings referred to are reducing pipes, " Y " pieces and bends where the branches are welded on to the mains of adequate diameter. No leakage is, of course, possible at the welded joint.

The hose couplings should be, of course, the self-sealing type with bayonet or like connections.

Valves of the rubber diaphragm type should be used where the gland of the spindle is not in contact with the air passage. This valve is highly suitable for coupling up to auxiliary pumps, fans, haulages, conveyors, coal-cutters, gate-end loaders, pneumatic picks and drills, etc.

Screwed type connections should be replaced by self-sealing connections, which pay for themselves in economy of compressed air.

PRESSURE GAUGES

Pressure gauges fitted to the pipe line in different districts in the pit, can be of real value and service, giving an indication of the " balance " of the system as a whole.

WATER IN MAINS

Drain-off valves can be usefully employed, inserted in the ranges at suitable points, to drain off accumulations of water created by condensation in the pipe line.

A good plan when connecting machines to the main, is to take connections off the top of the pipe range where possible, to avoid " water carry."

Water extractors, or aridifiers, inserted in the line when servicing auxiliary apparatus, are of beneficial use in the operation of movable machines, such as coal-cutters, conveyors, loaders, pumps, fans, haulages, pneumatic picks and drills, because of the relatively dry air finally used.

Freezing is also minimised by the use of the water extractor.

LUBRICATION OF COMPRESSED AIR MACHINES

The normal lubrication of underground machines leaves much to be desired.

A system, well organised and integral with an operator's duties should be established, whereby the responsibility of lubricating the machine under the operator's control is clearly fixed.

Damage to machines, e.g. seized bearings, stripped teeth, burnt teeth, etc., are of common occurrence and due entirely to lack of lubrication.

Spare parts are expensive and in short supply.

Pinning down the responsibility for the above incidents is not easy, unless an organised system is established.

It is suggested that with an organised system the breakdowns mentioned above will be greatly minimised, and the output of coal assured.

EFFICIENCY OF MACHINES

Periodically, the maintenance staff should fit flow meters as near to the machines as possible to check the consumption of air by the machine and thereby determine its efficiency and whether the machine should not be replaced by a new or overhauled machine.

All machines, new or overhauled, should be tested on the surface, the results tabulated and a copy of such tests handed on to the underground maintenance staff for future guidance.

UNDERGROUND PREPARATIONS TO RECEIVE PLANT

So much for the machinery side. What about the mining side and the preparations necessary to receive the plant and pipe lines underground ?

UNDERGROUND ENGINE HOUSES

The layout of machinery houses should have careful consideration.

Machinery, expensive as it is, should be housed, if it is to do its job efficiently, in such a manner as to afford protection against mining conditions, such as movement of the strata generally, bottom heaving and roof weighting.

There should be adequate access, ventilation and lighting, in order that breakdowns or repairs can be carried through in a minimum of time. With good lighting the operator can not only carry out his work efficiently and in so doing also be able to detect any fault or defect in time, but possibly save a major shut down.

PROTECTION OF PIPE LINE THROUGH WALLS AND PACKS

The passing of pipe lines through brickwork should have attention in order that the main is not crushed, due to weight of roof acting through the brickwork.

Openings through the walls can be left to accommodate the pipe and these can be sealed with sand or rubble, brickwork sealing both sides of the wall from the floor, but not being continued to the ceiling, only covering the actual location of the pipe line.

As a district develops, consideration should be given to the size of the roadways to accommodate the increased and final diameter of pipes to be used.

No greater example of the uneconomic use of compressed air can be found than to call upon machines to give an efficient output with a reduced pressure of compressed air, due to wire-drawing, because of the inadequate diameter of pipes in service.

This happens quite frequently with resultant slow cutting, which finally interrupts the cycle of face operations and more often than not causes a loss of output.

Ventilation of in-bye compressor houses should have special care in order that no build-up of temperature is possible in the engine house.

PIPE LINES

Compressed air mains, particularly the main out-bye ranges up to districts are afforded greater protection in the return airways, provided adequate inspection is carried out to ensure the pipe line is intact.

In the interests of floor space the ranges should be carried from the roof by hangers.

When this is not possible, care should be taken, when laid on the floor, to see that the pipe line is accessible in the interests of quick repairs when necessary, and also for water drainage purposes.

The practice of loose stones being stowed behind pipes is inexcusable. It leads to trouble and costs extra time to re-line and bring the joints together for coupling up when damage to a pipe line occurs.

DEPARTMENTAL

The manager will do well to discuss his development plans with his engineering department, who should be responsible for the efficient and economical application of compressed air, and not to leave the matter to the fitter, operator and underground official to achieve at the last moment. The engineering department should be brought right into the picture at the beginning of operations, not merely in emergencies.

Give them a chance to scheme and organise their work in such a manner that the manager and his planning department achieve 100 per cent. results from all their endeavours, schemes and planning.

EDUCATION

Care must be taken to educate all operators in their job. Not all who operate are mechanically minded, but with careful tuition most of them can become quite efficient.

All connected with the compressed air system should be kept in the picture week by week and so create a sense of pride and importance in their respective individual jobs.

CONCLUSION.

Whilst it is hoped that these notes will lead to the efficient and economic use of compressed air, the use of in-bye compressors should be always borne in mind in preference to surface compressors.

Further, and more important still, where possible, the use of compressed air should be eliminated altogether in favour of electricity. Where present-day plant is compressed-air operated, either on the surface or underground, the possibility of using electric power should be investigated immediately. It is suggested, with very few exceptions, that upon such investigation a case for immediate electrification could be established.

With a reasonable future life of a pit, the cost of electrification should not be allowed to interfere with such an undertaking. The cost of such a scheme would be paid for in a surprisingly short time. The plant can be used again elsewhere.

6. Efficient Mine Pumping

By A. W. KIDD, B.SC., A.M.I.E.E.

The subject of mine pumping falls into two divisions :—

(*a*) Face and roadway pumps.

(*b*) Pit bottom pumps.

FACE AND ROADWAY PUMPS

These situations call for a pump capable of dealing with a varying make of water and suitable for operating against different heads. The pump must also be able to go on snore and be self priming.

In some collieries, particularly in South Wales, compressed-air driven reciprocating pumps are used in large numbers for this type of duty. They have the advantages of being simple, fairly reliable and easily transportable within the mine, so that colliery managements have tended to favour them. But when operating costs are examined the picture is deplorable. It is not unknown for the overall efficiency of such a pump, i.e. the work put into the water divided by the work put into the air compressor at the pit top to be less than one per cent. Leakages of air in the supply column and leaky packing glands and valves all add their quota to the shocking waste. In one test made some years ago it was found that of all the compressed air sent down a certain colliery no less than 78 per cent. was absorbed by leaks and pumps. This may mean a loss of over £20 a day in power costs.

Therefore, if at all possible, all in-bye pumps should be electrically driven. For fixed situations where there is a large make, orthodox centrifugal pumps may be used, but for the ordinary roadside or face pump one can use either a reciprocating pump or a hypocyclodal screw pump, either of which has positive displacement and is self priming. One very convenient form of reciprocating pump is mounted on a pair of skids and has a single reduction gear running in an oil bath. It is totally enclosed and splash lubricated, and has a Vee-rope drive from the motor which sits on an extension of the skids. These pumps can be float-controlled and made entirely automatic to minimise attention and to cut out light load running losses when on snore. They are very economical overall.

Assuming electric power to cost ½*d.* a unit and relative efficiencies of 5 per cent. and 50 per cent., one could afford to spend about £3,500 to replace a continuously running compressed-air driven pump by a 5 h.p. electric pump, assuming the new installation has to pay for itself in five years. The annual fuel saving represented by this example would be not less than 175 tons a year. As a large colliery may have up to a dozen of such pumps the importance of electrifying in-bye pumps is apparent.

PIT BOTTOM PUMPS

No matter how theoretically ideal an installation may be, all pumps require regular and correct maintenance. For instance, sediment from contaminated pit water may greatly increase the frictional loss in the rising columns and corrosion of the impellers and diffusers may take place. If the storage sump is badly laid out, foul, grit-laden water may be drawn into the pump and cause undue wear and consequent interstage leakage. It is therefore good practice to instal a properly designed permanent V-notch at some convenient point in every installation, and record value of delivery and power consumption from which to determine the rate of deterioration of pump performance and the limit of economic operation at which the equipment should be reconditioned.

The correct selection of a main pit bottom pumping scheme is a problem of some complexity necessitating the careful balancing of many factors.

There must obviously be adequate pumping capacity under all predictable circumstances to ensure safety of the pit, and this involves having an ample safety margin.

To secure the best pump efficiency, in general the larger sizes should be installed, as pumps below about 30,000 g.p.h. fall off rapidly in efficiency. For example, two 30,000 g.p.h. pumps running together cost £25 per 1,000 hours more for power (at ½*d.* a unit) than one 60,000 g.p.h. pump. Furthermore, large pumps do not cost so very much more than small ones. For example, a 60,000 g.p.h. pump set complete with motor, lineswitch and accessories only costs about 33⅓ per cent. more than a 30,000 g.p.h. pump set.

It is important to have adequate shaft columns, both from the point of view of reliability and also to keep frictional losses to a minimum. There should generally be two columns in parallel of sufficient size to give a friction loss of not more than 2 per cent., with one pipe only in use, the figure of 2 per cent. being based on new pipes without allowance for ageing.

The crux of the problem of pit bottom pumping is adequate water storage capacity. Storage should be measured in hours and is the time for a sump to fill with all pumps stopped and maximum make flowing in. It can be demonstrated that with single-shift pumping one requires a minimum of 20 hours' storage, 12 hours with two-shift pumping and 4 hours with three-shift pumping. These are minimum figures to which anything up to 12 hours may be added for a colliery depending for its power supply on long and vulnerable transmission lines.

Underground storage will cost from 24*s.* a 100 gallons, depending on the nature of the strata, and in a pit handling, say, 1,500,000 gallons of water a day by means of two-shift pumping, the minimum storage of 12 hours would cost £9,000.

What form should a pumping installation scheme take for maximum economy ? From a prior analysis of the subject three-shift pumping may be ruled out as uneconomic unless there is some really quite insurmountable difficulty in making adequate underground storage. We are left, therefore, with single-shift and two-shift schemes.

The normal daily electrical load curve at a colliery has a hump during the day shift. The load factor may vary from 40 per cent. to 65 per cent. In general the maximum demand charge may be taken at £3 10*s.* 0*d.* per kilowatt per annum and therefore anything that can be done to reduce the hump, i.e. increase the load factor and decrease the maximum demand, is very well worth doing.

Pumping is the only colliery load of any size which is flexible, so that while loads such as winders, compressors, coal preparation, etc., cannot be moved from one shift to another, pumping load can be made to come on whenever most convenient and economic. Yet it is very frequently found that pumping is done during the morning shift. When one enquires the reason the engineer will say that he has insufficient underground storage ; that the water is wanted by day for the washery or that everything possible has already been done to reduce day shift pumping. Such replies often show a lack of appreciation of the true economics of the case. As an example, take a colliery with an installation of two 1,000-ft. head, 60,000 g.p.h. pumps of which one works each day from 7 a.m. until 2 p.m. The pumps would be about 80 per cent. efficient and would absorb about 400 h.p. each. By taking this load off the maximum demand a reduction of nearly 300 kW would be realised showing an annual saving of £1,050 in M.D. charges. Assuming a figure of 8 per cent. per annum for capital and maintenance charges, one could afford to spend just over £13,000 on a storage to achieve this result. In point of fact, however, a 20-hour storage for single-shift pumping of this amount of water would be unlikely to cost more than about £4,200 so that the net annual saving allowing also for higher wages of the pump attendant (14 per cent. more for afternoon and night shifts than for day shift) would be about £670.

But supposing 200,000 gallons of this water were required during the day shift for the washery. This in no way makes the proposition invalid, for a 200,000 gallon concrete storage tank could be made on the surface for about £2,100 so that the net annual saving would only be reduced by about £170, making it still £500 per annum.

It may be said that £500 per annum is not worth so much trouble to save, but this is taking a short view, and it may be pointed out that over large groups of collieries the policy of keeping all main pumping load off the morning shift improves the load factor by at least 15 per cent. and pays for itself much within the life of the plant and work involved.

This policy is particularly important where the power is generated in colliery power stations as the reduction in maximum demand enables other commitments to be made. Furthermore, by levelling the load curve the plant can be operated more efficiently and continuously since a bad load factor will lead to troubles. These may be such things as heavy repairs to boiler brickwork due to continual expansion and contraction, expansional trouble on boiler water tubes, turbine blades and alternator field windings. Moreover, a more even load curve enables generators to be operated for more hours at or about their economical rating instead of fluctuating from M.C.R. to quite low loads, and this alone may effect over 2 per cent. greater efficiency of generation.

My recommendations in concluding are simple, and they have the advantage that they pay well for carrying out :—

(1) Try to use nothing else than electrically-driven in-bye pumps.

(2) Use the biggest pumps and shaft columns that will fit the conditions, not the smallest.

(3) Keep all pit bottom pumping off the morning shift.

(4) See that every main pumping installation has convenient means of checking the pump performance regularly.

At the present time the nation is short of fuel and power. It is just possible that by excavating a new storage heading in your mine, you will not only be saving money yourself but also enabling a factory miles away to keep working.

7. The Reclamation of Fine Coal by Froth Flotation

By JOSEPH STAFFORD, M.I.MECH.E., M.INST.F.

Not less than 1 per cent. of the output of the Yorkshire coalfield is estimated to be discarded or burned inefficiently in excess in the form of washery slurry. If this proportion holds generally over other coalfields, there is available in the country a source from which the usable output can be increased by 2,000,000 tons. It is better to upgrade this slurry to a product suitable for efficient utilisation, either alone or blended than to attempt to burn it in special furnaces. The existence of these slurries has, in the past, retarded the application of high-efficiency boiler plant at collieries ; upgrading them removes this obstacle.

A vacuum flotation system (c.f. Proc. of B.C.U.R.A. Conf. on " Utilisation of Small Coals ", p. 233) is in use for this purpose at certain collieries. This system has the mechanical advantage of no moving parts, but it has the disabilities of being limited to one reagent feed, one pass through the cone, no provision for re-circulation of froth, and no draw-off at intermediate stages. On the other hand, although the froth flotation system employs high speed revolving units subject to erosion, the control of the washing in stages results in a cleaner product, and it is considered that the process advantages outweigh the mechanical disadvantages.

The plant installed at the Grimethorpe Colliery of The Carlton Main Colliery Co., Ltd., is of the froth flotation type, employing nine 35-in. × 35-in. K and B cells, the froth concentrate being de-watered on a 150 sq. ft. Kitson rotary vacuum drum filter. It is designed to deal with minus 1/20-in. solids, and to produce 10 to 12 tons per hour of filter cake, with an ash not exceeding 8·5 per cent. and a moisture content of 25 per cent. to 30 per cent. The raw slurry feed to the plant was assumed, for the purpose of guarantees, to have a solid content of 18 per cent., and the solids an ash content of 22 per cent. The slurry to be treated is pumped in one lift to a height from which it can flow by gravity through the whole plant, until the filter cake is produced and falls on to the larger products, by which it is absorbed. The plant is housed in an annex to the main Baum washer building. Space was provided for it on an upper floor, over existing smalls and fines coal jiggers (c.f. Iron and Coal Trades Rev., Sept. 6th, 1946, p. 415).

The plant was started up in November, 1945, and has been in continuous operation since, producing from 450 to 550 tons of filter cake each week, increasing the saleable output of the colliery by 2 per cent. or more. The waste from the plant is a milky thin slurry, carrying with it about 40 tons per week of free coal—fine particles eluding the process.

It is interesting to record that no de-dusting plant is in use at Grimethorpe Colliery, and that results appear to confirm that none is necessary ; a very satisfactory conclusion in view of the growing practice of wet cutting and loading underground.

Experience with the Grimethorpe plant leads one to say, contrary to what has been said elsewhere, that froth flotation of fine coal is not a supersensitive device, but a practical engineering process capable of control by any semi-skilled intelligent operator. Two men very easily control the Grimethorpe plant with plenty of time to swab decks and polish brasses. Incidentally, all motors are remotely controlled from a desk on the cell platform, overlooking the filter plant.

Nor is the process a costly one. The frothing reagent, in this case, costs no more than 3*d.* per ton, and is a very small part of the operating expenses. Considerably higher cost of reagent, when dealing with more difficult coals, is obviously permissible before the operating expenses are seriously affected.

The power requirements are not heavy ; the cells each take about 3½ h.p. only. The power taken by the plant when working to full capacity is approximately 100 h.p.

Operating expenses, when producing an output of 480 tons per week, amount to about 3*s.* per ton of filter cake produced. Amortisation charges will increase this cost by 9*d.* to 1*s.* per ton, depending upon whether or not a building is to be found. The plant has a capacity of 50 per cent. in excess of its present output, and any increase in output would, of course, be followed by a lower cost per ton.

The approximate cost, today, of the Grimethorpe plant, including slurry pumps, conditioner and cells, filter, vacuum pump, all tanks, piping, valves and accessories, also all electric motors, switchgear and cables, would be in the region of £15,000 erected.

Discussion

Mr. James F. Smith, speaking as an engineer to an electricity supply company, supported Mr. Walker's advocacy of colliery electrification with supply from the Grid. There was far too much obsolescent plant at collieries—steam-driven winding engines, air compressors and low-pressure (100 lb. sq. in.) boilers, making no pretence to anything other than an extremely low thermal efficiency. If collieries adopted the central power station proposal, possibly in conjunction with central washeries, the power station should be operated by a power company because, as one reason, the plant could then be run at a much higher load factor ; the margin of stand-by plant needed would also be less.

Dr. J. J. Hirst mentioned that seven froth flotation plants had been installed for the treatment of slurry. Whilst there was generally no difficulty in treating slurry in this way it sometimes happened that where the dirt was " clayey " in nature separation might be very difficult. It was generally possible to determine this in advance.

Mr. A. H. Dean believed that froth flotation plants had not been more generally installed because of a mistaken belief that they were difficult to operate. He had found, with a vacuum flotation plant, no insuperable difficulty in treating the more difficult slurries. Attention was drawn to the treatment of existing weathered slurry dumps by this method for recovery of coal. At one such plant 12 tons of current slurry and 3 tons of weathered slurry were treated in a 16-hour day, the product being used on the boilers. So successful was this that the plant now worked 24 hours a day, treating weathered slurry only on the night shift. The latest plant erected by the speaker's firm worked in conjunction with a 125-ton Coppee washbox treating coal below ½-in. and reduced the ash content of the slurry (through ½ mm.) from 15·5 per cent. to 6 per cent. The ash content of the refuse was 55 per cent. The treatment of slurry in this way was neither difficult nor costly.

Dr. E. T. Wilkins agreed that it should be possible to ascertain in advance when a slurry was likely to be difficult to treat. High-rank coals were comparatively easy to treat but low rank coals were likely to be more difficult as the oxygen content had been shown to have a deleterious effect.

Dr. A. Crawford urged that, with modern methods of coal preparation, there was no room in the future programme of the mining industry for low-grade fuels at all. The ash should be removed from the slurries and the effluents as well as from the nuts and large sizes, and if necessary the slurries and the effluents should be dried either by mechanical means or by thermo treatment. The problem then boiled down to one of size. The difficult fine sizes should be consumed at the central electricity generating stations in the coalfields ; the larger sizes could be transported to the more distant points of utilisation. We were on the eve of a new era in the mining industry, and men of vision should deal with the problem of the surface plant. He looked forward to the time when there would not be a 100-ton washer here and a 150-ton washer there, but centralised washeries as well as centralised generating stations. The capital expenditure on the central plants would be less than the aggregate on the emaller cleaning plants all over the country ; further, we should eliminate the spoil heaps which marred the countryside, particularly if the central cleaning plants were near the sea, because the sea would form the most convenient dump for the colliery refuse. The generating stations in the coalfields should be part and parcel of the centralised cleaning plant and could possibly burn the fuel in the pulverised form, which would enable them to use the widest range of fuels possible. If any sizes produced at the central cleaning plants became a drug on the market, they would be pulverised and burned in the generating stations.

Mr. Myers asked if Dr. Crawford had considered the effect of rail freights on the proposal for centralised cleaning plants. What would he do with the middlings ?

Dr. Crawford replied that the influence of rail freights must depend on circumstances. The type of coal was a governing factor in the treatment of middlings. For steam coals, the answer would be to crush the larger middlings, above, say, 1-in., and return the crushed coal to the cleaning plant. The refuse released from false middlings would be thereby removed and the true middlings would become dispersed in their rightful place among the steam coals. Middlings were objectionable in coking slacks as they were of poorer coking quality and higher in ash ; and outlet must be found for these middlings for steam raising.

Mr. W. T. Summers said that the use of cleaned fines for admixture with coking slack required the reduction of the moisture content to the lowest practicable figure. The moisture content of this class of material was in general controlled by the −100 mesh fraction, but in a vacuum flotation unit this fraction was not cleaned so effectively as larger, say, 60–100 mesh coal. The efficiency of recovery of clean coal was ascertained from the ash balance on the feed, clean coal and rejects but there was evidence that this method was not entirely satisfactory and that the mineral matter content should be used instead. The vacuum flotation plant had been worked with two or more reagents, the reagents being introduced together.

Mr. Simpkin, referring to the difficult labour conditions in connection with the utilisation of low-grade fuels, and to the consequent use at collieries of some fuels of good quality which normally would be sold, urged that if plant could be designed for the better handling of the low-grade fuels, in order to avoid the heavy manual labour, much of the low-grade fuel could be utilised more effectively. It was possible in many cases to mix low-grade fuels with other fuels. But the very widely fluctuating loads in collieries rendered it necessary at some periods to run on good clean coals, and the low-grade coals could be used only when the demand for steam was considerably lower.

Mr. Budd said that in his experience it was unsatisfactory to deal with slurry in the form of filter cake. The efficiency of utilisation was low and constant supervision of the men was needed. To produce slurry with 20 per cent. moisture and 20 per cent. ash was not good enough as it could not be got into and out of the bunkers ; nor was it satisfactory to mix this material with other coal. If slurry must be used its moisture content must be reduced to 13 per cent. and then it would be suitable for use on a chain-grate stoker.

Mr. Partridge believed that there should be no such thing as unsaleable coal, as if coal would raise steam at collieries it would raise steam elsewhere. In his experience blended fuels burnt better than the constituents separately. To demand low-ash coals for steam raising was essentially wrong and resulted in burning out the stoker bars ; fuels with an ash content of 12–14 per cent. were quite satisfactory for the purpose. He favoured the central washing, blending and electrical generation plant proposed by other speakers since a straight-line fuel could be produced without the need to worry overmuch about 2 or 3 per cent. more or less of ash. There was difficulty in designing combustion chambers owing to the large amount of nitrogen to be carried through the system ; the use of oxygen was a possible line of development. He mentioned an American boiler plant with a high heat release in the combustion chamber up to 500,000 B.Th.U./cu. ft.

Mr. P. J. Meadows commenting on a remark that consumers should accept higher ash content for the sake of stability in ash content, pointed out that in South-East England the cost of fuel transport was very high indeed, and it seemed to be essentially bad to move inerts about the country. Unless each colliery in a district produced coal to a particular ash standard, a consumer who received one week's coal from one colliery and the next week's coal from another would still experience trouble due to variation of ash content.

Mr. W. E. Raybould reported briefly on the work of the South Midland coal preparation panel. Owing to the high oxygen content of the coals in this region and the presence of finely-dispersed fireclay, the slurries were not amenable to the froth flotation methods outlined by Mr. Stafford. At many of the South Midland collieries the underflow from the wedge wire screens was run off as an effluent ; in consequence the material deposited in ponds usually contained between 25 and 50 per cent. of fine granular coal, over 60 mesh, having an ash content of about 10 per cent. At the present time the panel was interested in tests being made by the Fuel Research Station, using a Dorr Classifier to ascertain the possibility of recovering some 60,000 tons of this material from settling ponds at one colliery. It was vital that temporary expedients of that character should be adopted while plants were being modified to avoid deposition of coal in slurry ponds. The system of running such material into ponds for subsequent recovery was wrong and he advocated the adoption of an alternative point of discharge from the washing system where this coal had an opportunity to settle out. He considered also that another wide field existed for the recovery of adventitious coal from ripping dirt, which was not tipped at the screens but transported direct to the dirt mounds. Hand picking from the tops of the tube had effected a small recovery, but the only really satisfactory solution was a separate picking belt for all pit dirt.

Mr. A. D. Cummings wrote urging that attention should be paid to the suggestion made by Dr. Jones that a panel of colliery chemists in each area should advise the local Coal Board upon the optimum ash contents for the cleaned coals in that area ; by reducing the ash figures too much, valuable coal and middlings were lost. Whilst the recovery of fines had created much interest, the problem of what to do with the fines when they had been recovered was unsolved. They made the boiler fireman's work very heavy. He considered that the only satisfactory method was to blend fine coal with the washed slack in such a way as to produce a coal of uniform ash and moisture content ; this mixture would not cause trouble on boiler grates.

Mr. H. Jackson wrote that the production of low-grade coals should be reduced to the absolute minimum, though there were circumstances under which their production could be justified. Most of the low-grade fuel above ½-in. came from belt pickings, bands and middlings. This should be crushed and re-washed with the ½-in. smalls. Low-grade coal below ½-in. was confined to the fines—dust, duff, slurry, etc. Intensive underground mechanisation and mining of poorer and banded seams would lead to the production of more of this class of coal so that the problem of dealing with low-grade fines would be aggravated. Demands by large consumers in the past for coal not in general supply had led to the production of low-grade fuel for which there was only limited outlet. The writer advocated the re-mixing of fines treated or untreated according to quality with the cleaned small coal. A responsible representative of the appliance manufacturers had stated they could burn efficiently anything that could truthfully be called coal. The consumer should sacrifice his fetish of high thermal efficiency in favour of a more economic balance between efficiency and maintenance. Consistency of quality and size being assured, he could modify his existing handling equipment, where necessary, to promote the use of standard fuels. That would be a long-term policy, but a policy that could be immediately put into effect would be to restrict to a few types the multiplicity of fuels being supplied for steam raising.

Mr. J. S. Wilding wrote calling attention to the work that had been done in dust-proofing coal in preparation for the market by spraying it with a petroleum oil, generally a fuel oil of medium viscosity, to the extent of 5–15 lb. of oil per ton of coal, the amount varying with the size and rank of the coal being treated. This method in addition to eliminating dust was also claimed to suppress the segregation of the fines.

Mr. S. Collin Swallow and **Mr. C. Oxley** also spoke.

THE CHAIRMAN of the Section, **Professor D. T. A. Townend,** summarised the major conclusions from the discussions of the section as follows :—

The three sessions dealing with the light and heavy clay industries, the railways and the coal industry have been most enthusiastic and have brought out two points of similarity which are not always fully appreciated :

(1) The necessity of choosing the right equipment to suit the particular purpose and the fuel available ; and

(2) The necessity of maintaining that equipment in first-class condition.

If those two factors are borne in mind, considerable fuel savings can be achieved.

In the light and heavy clay industries, considerable research has been carried out on continuous tunnel kilns and these are now replacing the less efficient, hand-fired kilns for many purposes. The use of continuous tunnel kilns must be combined with production planning to ensure a steady flow of ware from the kiln, and the industry must concentrate further effort towards improving both the design of these kilns and the special fuels which can be used to fire them. Research must be continued into the methods of drying the ware, packing it into the kilns, and the influence of rate of firing, which steps, combined with proper heat insulation, will help to ensure that fuel is turned to useful account.

The railways use about 14 million tons of coal a year and locomotive designers are required to fit a great deal of powerful and intricate machinery into a very small space. For this reason, the balance between low fuel consumption and high output is a delicate one. A steam engine will handle heavy overloads without much complaint, but its efficiency drops rapidly if it is asked to do so. The proper planning of work and loads for each engine is essential. A powerful locomotive drawing an express train at high speeds can burn coal relatively economically. Equally essential is regular mechanical maintenance. The railways have to consider the best engines and the best fuels to use for each duty that has to be performed and, apart from the use of oil and electricity, research should be carried out to increase the efficiency of the steam locomotive above its present percentage. Skill on the footplate is an important factor and may effect a fuel saving up to 15 per cent. The railways, we are assured, will continue to encourage and instruct their staffs to this end.

The coal industry may be said to regard its fuel efficiency target as the elimination of the words " unsaleable coal " from its dictionary. The task is twofold. Firstly, the improvement of low-grade coals, either by cleaning them or by blending them with better fuels and, secondly, the efficient production and use of the power required in the pits. Slack which was previously described as refuse can now pass through cleaning plants and produce considerable quantities of saleable coal, and this process should be extended, possibly by the erection of a central washer that would serve several pits, where such a procedure is economic and technically feasible.

There is an urgent need for a suitably designed mechanical stoker to fire boilers with low-grade fuels and blends, and it is of the greatest importance that collieries should avoid heat and power losses by the proper maintenance of steam and compressed air lines. In some cases it might seem preferable to generate electricity in a power station which is adjacent to a central cleaning plant, rather than in individual power stations at collieries.

The fuel efficiency problems of the coal industry are also, of course, intimately connected with the proper sizing and grading of coal, and they, just as other industries, are concerned in choosing their equipment to make the best use of the sizes and grades of fuel which will be available.

JOINT SESSION I

THE SIZING AND GRADING OF COAL

Chairman: MR. J. C. GRIDLEY, C.B.E.

MEMBER OF THE NATIONAL COAL BOARD

THE CHAIRMAN referred eulogistically to the work of the Coal Grading Committee of the British Colliery Owners' Research Association, whose report on coal sizes was to be discussed at this session. The tenacity with which the average home buyer had clung to particular brands and narrow sizes was a substantial reason for the delay in bringing about standardisation of sizes. The necessity to produce a great variety of grades and sizes, often from a single pit, has been one of the reasons for the industry's small-scale preparation operations. In the future it seemed that buyers would have to choose between a much narrower range of grading and size if they were to make their contribution to the efforts of the Coal Board to enlarge production units and so reduce costs.

1. The Report of the Coal Grading Committee

Mr. W. McGilvray (Chairman of the Committee) then introduced the report of the Coal Grading Committee. The report had for its object the removal of confusion and ambiguity in nomenclature and this, he hoped, had been done by giving a definition of large coal and proposing seven sizes for graded coals and six for smalls. (The system of size classification and nomenclature proposed is reproduced here from the report.)

SYSTEM OF SIZE CLASSIFICATION AND NOMENCLATURE

LARGE COALS

Large coals (having no upper size limit) are to be described in terms of the size and shape of the aperture of the screen over which they are made.

GRADED COALS

Graded coals (made between two screens) are to be classified in seven standard size groups. Each group contains coals for which the upper and lower sizes of screen aperture both lie between the minimum and maximum limits given in columns 3 and 4 of Table I.

Large cobbles and cobbles should be screened, conveyed and loaded in accordance with good colliery practice. Where dry picking is practised, guard screens should be used immediately before loading and they should be 3-in. round (or 2½-in. square) for large cobbles and 2-in. round (or 1½-in. square) for cobbles. Washed varieties should be adequately sprayed and drained.

For trebles, doubles, singles, peas and grains two criteria of undersize, as determined by sieve analysis, are given in columns 5 and 6. These limits allow for variations of screening efficiency and the errors of sampling. With good practice a colliery should ensure that the *average* product does not contain more than *half of the limiting quantities* of undersize given in Table I.

The names given in column 1 are to be reserved for coals satisfying the above conditions.

TABLE I

STANDARD SIZE GROUPS FOR GRADED COALS

Name of group (1)	Typical screen size (in. rd. hole) (2)	Permitted range of screen apertures (in. rd. hole)*		Criteria of undersize—neither to exceed	
		Upper limit (3)	Lower limit (4)	A.† (5)	B.† (6)
Large cobbles	6 × 3	6 to 8	3 to 5	—	—
Cobbles .	4 × 2	4 to 5	2 to 3	—	—
Trebles .	3 × 2	2½ to 3½	1½ to 2	15 per cent. through 1¼ in. sq.	2 per cent. through ¼ in. sq.
Doubles .	2 × 1	1¾ to 2¼	1 to 1½	25 per cent. through ⅞ in. sq.	3 per cent. through 3/16 in. sq.
Singles .	1 × ½	1 to 1½	½ to 1	20 per cent. through ⅜ in. sq.	3 per cent. through ⅛ in. sq.
Peas . .	½ × ¼	½ to ¾	¼ to ½	15 per cent. through 3/16 in. sq.	3 per cent. through 1/16 in. sq.
Grains .	¼ × ⅛	¼ to 7/16	⅛ to ¼	25 per cent. through ⅛ in. sq.	3 per cent. through 1/32 in. sq.

* Appropriate equivalent square apertures which may be used.

In. rd. hole	8	6	5	4	3½	3	2½	2¼	2	1¾	1½	1	¾	½	7/16	¼	⅛
In. sq. hole	7	5¼	4¼	3½	3	2⅝	2⅛	1⅞	1¾	1½	1¼	⅞	⅝	⅜	⅜	¼	⅛

† These square meshes refer to those defined in B.S. 410 and are to be used for the determination of sieve analyses as required by B.S. 1293.

Note.—The Committee anticipates that the process of evolution of screen sizes will bring them as near as practicable towards the typical sizes.

SMALLS

Smalls (having no lower size limit) are to be described in terms of their treatment and the size and shape of the aperture of the screen through which they are made. In addition, smalls are to be divided into classes according to their fines content, as indicated in Table II.

TABLE II

DESCRIPTION OF SMALLS

Treatment.
Size and shape of aperture.
Fines content in class :—

Classes for Fines Content	Described as
0–15 per cent. through ⅛ in. sq. mesh	15
15–25	25
25–38	38
38–55	55
55–75	75
75–100	100

Any particular smalls should be placed in the class of fines for which the upper percentage is only exceeded once in twenty times. For example, if the fines content of individual consignments frequently exceeds 25 per cent. and 19 times out of 20 does not exceed 38 per cent. then the smalls lie in the 38 per cent. class.

OTHER COALS

With other coals, which cannot be described as above, the mode of preparation should be stated. Alternatively a full sieve analysis may be given.

The term " slurry " is to be restricted to the wet material passing ½ mm. wedge wire screens (50 B.S. mesh).

DETERMINATION OF SIEVE ANALYSIS OF ALL COALS

Samples for sieve analysis should be taken as nearly as possible to the condition " as loaded " at the colliery screens and sieved in an approved manner as described in British Standard 1293. British Standard Test Sieves as given in B.S. 410 should be used.

Mr. McGilvray went on to say that there was no point in attempting to standardise large coal, as most consumers broke it down before use. His view was that when the market became normal, the pre-war tendency to eliminate the large in favour of smalls and graded coal would be accentuated. The committee anticipated that the tendency would be for screen sizes to be selected at or near the typical sizes. The permitted ranges of screen apertures and criteria of undersize were generous. It was thought wise at the present stage to adopt a simple classification. Investigation of fines in small coal was proceeding and he hoped that ultimately a lower gauge than ⅛-in. would be acceptable. The name " nuts " had disappeared in the nomenclature proposed, because its use was confusing, covering a variety of sizes from trebles to peas. The committee recommended to the National Coal Board that the report be implemented as soon as possible.

Mr. R. L. Brown (Principal Investigator to the Committee) said that there were three facts on which the committee had based its scheme for coordinating the exigencies of production with the requirements of consumers* : (1) the sizes of screens in use at collieries fell into well-defined groups, (2) sieve analysis of two coals made with the same size of screen at the colliery showed a wide range of actual size, and (3) successive samples of a graded coal or smalls varied in sieve analysis. The first fact was found from a survey, which, however, achieved more than a mere grouping of sizes and included factors of supply and demand ; but the adoption of seven standard size groups did not in itself ensure that two qualities having the same name would have the same screen analysis ; for this reason it was necessary to introduce the further qualification of limits for the amount of undersize, determined by a fixed series of square-meshed sieves.

With smalls there was much discussion as to the possibility of stating the fines content. Investigation enabled a series of classes to be established for the fines content of smalls of different top sizes ; for example, smalls with a top size of 1-in. round typically had a fines content between 25 per cent. and 38 per cent. where the fines content was expressed as the percentage passing through ⅛-in. square mesh. These classes were used in constructing Table II of the report.

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* Full details are given in the Statistical Report on the Size Grading of Coal, issued jointly by the British Colliery Owners' Research Association and the British Coal Utilisation Research Association.

The proposed system had the following characteristics :—

(1) It removed the confusion and ambiguity in the nomenclature and description of graded coals.

(2) It limited the number of graded sizes to seven.

(3) It provided a criterion of good practice in the preparation of graded coals.

(4) It provided a standard method of stating the fines content of smalls.

(5) It was closely related to present practice in the industry.

The chief stumbling block to any system of size classification was the variability of the undersize in successive wagons or deliveries. Mr. Brown illustrated this by reference to the undersize in singles expressed as the percentage passing a ⅜-in. square mesh. The requirement was that the undersize should not exceed 20 per cent. The report recognised that there would be a certain degree of inconsistency between successive wagons and that if the undersize was 10 per cent. or less " only rarely would the outside limit of 20 per cent. be approached ". The operation of screening plant was recognised to be a variable process characterised not only by a figure describing the average product but also by a figure expressing the degree of inconsistency, called " the inconsistency factor ". A detailed study of the available data had shown that the inconsistency factor with singles was about 7½ per cent. If, then, the average undersize was 10 per cent., of 100 customers each receiving a single wagon, 50 would get a product containing between 7 per cent. and 13 per cent. of undersize, 70 would get a product covering the wider range of 5½ per cent. to 14½ per cent. undersize, and 5 would get a product containing more than 17½ per cent. undersize (i.e. average undersize plus inconsistency factor). There might be an occasional wagon containing more than 20 per cent. undersize.

When further data became available, the tolerances of the nominal sizes and the outside limits to the undersize should be revised. The proposals were cast in a form which would permit account to be taken of fresh evidence in the future.

2. Grading and Sizing in Relation to Production

Likely Future Trends of Production Technique

By T. E. B. YOUNG

MEMBER OF THE NATIONAL COAL BOARD

The policy for future production technique must be towards greater underground mechanisation. The use of the pick wielded by the miner has been greatly reduced, but the shovel as a means of loading coal manually still remains to the extent of 95 per cent. or more of all coal produced. This manual shovel must be replaced by the mechanical shovel.

These changes will affect both sizing and grading.

Firstly as to sizing : consumers generally are becoming more and more inclined to the use of smaller coal, and this will be accelerated by the trend towards greater coal face mechanisation. Mechanical processes of production tend to increase the proportion of undersizes and reduce that of very large lumps. But this is surely all to the good, for the first thing most consumers who insist on large lumps do before burning them is to break those lumps down to smaller sizes, and in the process they even break them down to fines. Uniformity of size and quality should be our objective.

Now as to grading. Grading means quality. It would be an exaggeration to say today that consumers generally are satisfied with the quality they are receiving. This is a situation which in time we shall hope to correct and indeed we must correct. To comply with consumer's needs for a closely-sized and uniformly good quality, together with the elimination of unnecessary labour, many new mechanical cleaning plants will be required, and this will take time. The mechanical loader in the pit has no discrimination in what it loads. It will load dirt or shale and coal with equal facility and it will load them all together. At some stage, therefore, between the coal face and the wagon, provision will have to be made for the most economical and effective separation and sizing. We must anticipate, with the intensification of underground mechanisation, the need for better cleaning arrangements.

The mechanisation of pits in its true sense will be a gradual process, and the provision of special grading arrangements will be synchronised with its development. In the meantime, it will be the duty and the purpose of the National Coal Board to ensure that existing plants are operated to their maximum efficiency, both as regards sizing and grading. Rather less than 5 per cent. of the coal output of the country is today produced by " true mechanisation " (i.e. power loading).

3. Grading and Sizing as Affecting the Export Market

By H. L. GREIG

BRITISH COAL EXPORTERS FEDERATION

Exporters are heartily in agreement with the report as a whole. The typical sizes are easily convertible into their millimetre equivalents—an improvement which will be of value in dealing with foreign buyers—in contrast with the present wide range of British descriptions, expressed often in small fractions of an inch. Standard grading has long been practised by Continental producers where the normal screen sizes for graded coals are :—120/80 mm. ; 80/50 mm. ; 50/30 mm. ; 30/18 mm. ; 18/10 mm. ; 10/6 mm. There are slight variations between the different producing countries but these sizes are substantially common to all resulting in consistent and evenly-graded products.

The British coal exporters have been only too well aware of the handicap placed upon them in competing against those Continental products. The simple nomenclature consistent with the uniformity and closeness of grading practised there gave our foreign competitors a great advantage as compared with British graded coals with their variety of names and wide differences in grading, not only as between districts, but also sometimes between collieries in the same district. In some instances similar sizes are sold under different names and in others—more confusing still—the same names are used for different sizes.

Our foreign competitors in their home or other Continental markets where they could deliver over land direct from the pits with a minimum of breakage, have enjoyed an inevitable and obvious advantage over our coals which are perforce seaborne, involving so much additional handling. In consequence, collieries in this country sometimes catered specially for certain customers on the Continent, whose business could not otherwise be secured, by making regular contracts for exceptional sizes. It will, no doubt, still be necessary in the future to deal with such exceptional cases and it is not intended that the adoption of standard size groups should preclude the production of special sizes where the necessity arises.

Prevention of segregation is important to overseas business. The greater the irregularity and the wider the margin of size, the more pronounced is segregation.

Careful screening of coals can be and often is more or less nullified by what happens after the coal leaves the screens. Suitable handling and loading appliances and their efficient use is a matter for close investigation in this country and there is much to be learned from a study of continental practice.

We shall in the future depend for success on giving efficient service and providing our customers abroad with coals in the most attractive possible condition. The fulfilment of the proposals contained in this report will be an important step in this direction.

4. Coal Grading in Relation to Marketing

Mr. L. Locket said that segregation was a very real difficulty to the distributor who had to ensure that one fortunate customer did not get all the nutty sizes and another unfortunate customer all the fines. Anything which tended to standardise the grading of coal must tend to eliminate segregation. In the past, domestic coal distributors had advised their customers upon the kind of coal suited to the appliance installed and had built up their business by providing that coal. Today they had no choice in coal selection and had to take what coal was delivered and send it out blindly, hoping for the best, sometimes even before the advice note had arrived. This position negatived the value of the work done on appliance design and led to fuel wastage. No distributor could be expected to know the characteristics of every coal in the country and any step, such as the implementation of this report, which would assist distributors in giving sound and proper advice to consumers must in turn have a very beneficial effect both upon research into and use of better and more economical coal-burning appliances.

Mr. J. K. Matthews spoke on the experience of size grading in the Lancashire coalfield. He congratulated the committee on laying simple foundations upon which other structures could be erected as experience dictated. It might well be, for example, that the significant fines would be those through $\frac{1}{16}$-in. mesh (or even less) rather than through $\frac{1}{8}$-in. At the inception in 1935 of a central selling organisation in Lancashire it was decided as a sales policy to call like things by like names and sell similar coals at the same price. When it was found that some grades of coal did not fall into any group it was decided that standardisation was desirable. The evaluation of coal was based upon all the relevant chemical and physical characteristics, including their size distribution, in regard to which the local research association had a mass of information. Mr. Matthews went on to describe the size grading and nomenclature set up in the Lancashire coalfield. Fines in small coal were regarded as a point of quality having a bearing upon price—like ash and sulphur—but the present report was better in that it brought the fines content into the size nomenclature. Large coal was divided into three groups : over 1½-in., over 2½-in. and over 4-in. Lancashire adopted the C.A.M.A. classification for graded coals ; this set out to cover almost any size that a colliery could make and in its comprehensiveness, unlike the B.C.O.R.A. report, contained no move towards a reduction in the number of sizes. Analysis of 302 Lancashire graded coals showed that 70 failed to comply with the permitted range of screen apertures as given in the B.C.O.R.A. report, but a comparatively small increase in the lower size screen or decrease in the top size screen would make all these coals comply with the specification.

Mr. R. J. Moffat said that the Midland Amalgamated District, unlike Lancashire, did not have a central selling scheme and although colliery owners were in favour of size standardisation, little progress had been made. This was partly because there was no simple standard to which they could work and partly because of the tendency of appliance makers to insist on very close grading of a multiplicity of sizes. Such close grading had been shown by war experience to be unnecessary.

Whilst appreciating Mr. Locket's present difficulties the speaker believed that there would be in the future orderly marketing of coal, not the hit-or-miss method which ruled today.

The report should have a lively interest for the domestic consumer. That class of consumer required a few well-defined grades of coal to choose from, with the certainty that having chosen a particular grade which was suitable for his appliance he could be reasonably sure that a repeat order would bring coal with the same characteristics. Domestic coal should be regular in size and contain not too much undersize. Reduction in the amount of undersize would assist distribution, and storage in modern houses where the limited storage space should not be congested by useless fines. The report should be welcomed on behalf of the domestic consumer as a practical document. It was indeed a practical document which set a reasonable measure of tolerance and a reasonable standard of checking at the collieries. But as progress was made in the technical re-organisation of the industry those standards could be tightened without departing from the basic principles of the report.

5. The Grading of Coke

By W. L. BOON, O.B.E.

Faced with the need to seek additional markets for coke, about 1930 a grouping of the gas coke producers in the South of England was formed to investigate and formulate methods of improving and marketing their coke. As a consequence, it was deemed essential that technical work be undertaken forthwith into all phases of coke utilisation and the qualities of gas cokes which it was necessary to produce for these purposes, the production of new and improved coke-burning appliances being a part of that work.

Gas cokes were standardised into four broad sizes—over 2-in., 2-in. to 1-in., 1¼-in. to ½-in., ¾-in. to ⅜-in.—which were accepted voluntarily by the majority of gas undertakings in the South, thereby replacing 50 different sizings previously produced. From the commercial angle it became obvious, too, that some stabilisation and co-ordination in price was necessary if the improved marketing of coke was to be carried out effectively. To achieve this stability, and a sensible degree of price co-ordination, the development of the four standards helped immeasurably.

So successful was this standardisation in the South of England that recommendations were made for the adoption of a national standard. A committee set up by the Institution of Gas Engineers issued recommendations which were accepted by the gas industry although their production must of necessity take place gradually as screening plants can be changed to conform to the sizes laid down. Nearly half of the gas coke production in the country is now sized to these standards and the limits of sizes which are provided have generally sufficed to take care of the different types of coal carbonised and the declared calorific value of the gas supplied. The recommendations were as follows :—

No. 1 No upper limit over 1¾-in.
No. 1A Within the limits of 3½-in. to 1¾-in.
No. 2 Within the limits of 2-in. to 1-in.
No. 3 Within the limits of 1¼-in. to ½-in.
No. 4 Within the limits of ¾-in. to ⅜-in.
No. 5 Unwashed fuel approximately ¾-in. to ¼-in. from which the fines up to ⅛-in. had been removed.

Note.—No. 1A was added after the other sizes had become well established, when re-numbering in sequence would have caused confusion.

Whilst it is true that satisfactory performance of coke as a fuel, particularly in the domestic field, depends upon other factors such as reactivity, physical structure, ash and moisture content, there is no single consideration so important as that of size. The worse the quality of the coke the more essential becomes its sizing.

From the coke consumers' standpoint, the improvement and development of appliances in which coke could be efficiently used, having progressed in parallel with the production of sized cokes, has very materially altered the whole aspect of coke sales, particularly in the domestic field. It is no exaggeration to state that since the adoption of the standard sizes of coke and the availability of suitable and efficient appliances, the efficiency of domestic utilisation has been doubled in little more than a decade. It is clear, therefore, that the value of sizing and the standardisation of sizes, coupled with the research which has taken place in utilisation, has been of immense benefit to the industry as a whole and no less so to the consumers of the product.

In the future, all gas cokes will have to be produced and sold competitively as sized products, with consequent largely increased production of breeze. The industry is, therefore, now actively investigating the dual problem of producing largely increased quantities of domestic sized cokes, and the reduction of degradation in the form of breeze consequent upon cutting, screening and handling. At least 12 per cent. of the total product is degraded to breeze in these processes.

Whilst hard coke is used largely for blast furnaces and foundries, the problems of cutting and screening apply to the lower sizes and to other coke remaining after the furnaces have been supplied. The hard coke industry has instituted, through the British Coke Research Association, investigations to the whole problem of cutting and screening as applied to the specification of hard coke sizes and the determination of the most suitable sizes for specific duties. The committee undertaking this investigation is considering proposals for recommending to the industry the adoption of five sizes of coke and breeze and giving such sizes appropriate reference numbers. It would seem, therefore, that the hard coke industry is separately but equally with the gas industry coming to a practical definition of five standard sizes. There is, of course, close co-ordination between them, which will immensely improve both the marketing and utilisation of their coke.

6. Industrial Coal

Lt.-Col. H. Rudgard representing the British Railways Central Fuel Efficiency Committee, said the railways in England and Scotland used over 14,000,000 tons of large coal per annum, of which about 2,400,000 tons came from South Wales. To use the South Wales coal satisfactorily it was necessary to have a specially-designed grate. Dynamometer tests on a locomotive using some twenty coals over 128 miles of track, showed increased consumption as the suitability of coal deteriorated. The difference ranged from 2·80 lb. to 4·12 lb. per drawbar h.p./hr.; the total consumptions were 6,720 lb. and 9,859 lb., respectively, an increase of 47·1 per cent. A proportion of small, slacky coals had a tendency to be pulled through the tubes and thrown out from the chimney, giving rise to the possibility of line-side fires, apart from the trouble caused by furring up the tubes. Coals were required for (*a*) express long-distance passenger trains running up to 400 miles; (*b*) long-distance freight services, necessitating long hours in steam, and passenger services; and (*c*) short-distance freight services and shunting. In deciding suitable coals for those conditions, the chemical analysis formed a useful basis for comparison. Normally, large size coal had disadvantages. The most suitable size for locomotives was a large cobble, 6-in. to 8-in. by 4-in. It would pass through coaling plants without undue breakage, and would reduce the work of the fireman on the locomotive, thus being more economical in use.

Locomotives had recently been put into service with self-cleaning smokeboxes, rocking grates and hopper ashpans, and the design of these grates made it possible for enginemen to break up the clinker in the firebox easily. At selected points on the line facilities were provided so that enginemen could use the rocker grate and hopper ashpan and so perform in a very few minutes what was a lengthy and arduous operation when done manually. Rocking grates should be designed to enable them to be rocked when running. The provision of the self-cleaning smokebox not only automatically emptied the smokebox as the locomotive worked, causing the emission of char in the form of dust, but also kept the tubes clean.

Devices had been evolved to prevent breakage of coal at coaling plants but without complete success, and it had been found that the most satisfactory results were obtained if the bunker was kept well filled, thereby reducing the distance the coal had to fall from the wagons. This was not always practicable because it was uneconomical to have a man hoisting coal throughout 24 hours, unless other work could be found for him, and in residential districts the railways might be under an obligation not to cause unnecessary noise during the night and therefore the bunkers were not replenished.

The most suitable grade of coal for express through passenger trains up to 400 miles, apart from South Wales coal, was a hard coal, either from the Barnsley or Parkgate seams, which produced a porous ash not excessive in quantity. For long-distance freight and services necessitating long engine-hours in steam, a dull, firm to semi-hard coal, or a mixture of this with a firm or semi-firm bright, was suitable. The coals used for short-distance freight services and shunting turns were generally of a more friable nature and contained a high percentage of ash ; this resulted in excessive firebox residue after a very low mileage.

Mr. T. F. E. Rhead, on behalf of the gas industry, welcomed the proposed reduction in the number of sizes and the simplification of the present confused terminology. That it was not essential for the gas industry to be provided with closely-graded coals was shown by the use in continuous vertical retorts in London of 1½–2 million tons annually of highly-swelling, crushed run-of-mine coal.

Horizontal retorts, in works possessing a coal breaker, did not require graded coal. The Fuel Research Station (Tech. Paper 26, 1930) showed that smalls below ¾-in. produced a higher quality of gas (20 to 30 B.Th.U. per cu. ft.) than graded coals without any reduction in thermal yield. On the other hand, the use of 100 per cent. dry smalls, say, below ¾-in., containing a high percentage of fines (below ⅛-in.) could cause trouble from dust being carried into the ascension pipes and tar mains, and with poorly caking coals led to dangerous flare at discharging times. If too wet, smalls and fines gave trouble in chutes, etc., and reduced retort temperatures. Coke-oven requirements were similar to horizontals, being admirably adapted for smalls, but the coal must have a swelling index of not less than 4 (B.S.I.) so that the coke could be discharged.

Since the incorporation of both top and bottom gas offtakes, intermittent vertical retorts would deal with any coal that could be used in horizontals. Variation in size, however, affected the output per unit of plant as follows, this falling off in output being due to run-of-mine coal having a greater density because of closer packing :—

Size of Coal	*Relative Thermal Output per unit of Plant*
Run-of-mine	100
Crushed screened coal below 3 in. . . .	97·5
Doubles (2 in. × 1 in.)	95·0

Modern designs of continuous verticals would carbonise crushed run-of-mine coal with swelling indices up to 9, but were very responsive to coal size, the following increases in output being possible because the improved porosity of charge facilitated quicker carbonisation, due to internal heating by uprising gases :—

Size of Coal	*Relative Thermal Output per unit of Plant*
Run-of-mine	90
Crushed screened coal below 3 in. . . .	95
Doubles (2 in. × 1 in.)	100

The porous charge also allowed better steam contact, which led to better steam cracking and a more reactive coke. There was a rough relationship between the desirable size of coal and the swelling index, and generally more smalls could be incorporated with the lower swelling-index coals without impairing the improvement of output. A suitable proportion of smalls helped to improve the calorific value of the gas.

Too great a variation in size range often adversely affected working results due to segregation. Smalls might retain so much moisture as to cause trouble in chutes and reduction of retort temperatures. Probably the greatest flexibility of coal purchase, and the greatest efficiency in working, lay with a combination of intermittent and continuous vertical retorts. The smalls below 1-in. could be screened out for use on the intermittents and the larger coal used on the continuous verticals.

Variability in size, particularly with the more highly swelling coals, led to working difficulties, especially with continuous verticals. These difficulties were greatly aggravated when coals of very different swelling properties followed in quick succession into the retort "sandwich" fashion. These difficulties adversely affected (1) control of retort temperatures and heat distribution, (2) wear and tear on refractories, and (3) coke quality. The overall effect was greatly reduced efficiency—leading to waste of coal. Constancy of supply as regards size and type of coal was absolutely necessary if high efficiencies were to be maintained. Coke was an important product of the gas industry and to secure adequate quality, constancy of size and type of coal was essential.

During the next ten years developments in the gas industry would reflect on the quality of coal required : (1) More attention would be paid to constancy in size and type of coals charged to the retorts ; (2) more attention would be paid to size and type of coal to give a coke of improved combustibility, etc., as a contribution to the solid smokeless-fuel market ; (3) endeavours would be made to use coals not at present employed for gas manufacture, especially those of lower caking qualities ; (4) more extensive installation of storage bunkers and mixing machinery would allow flexibility in choice and purchase of coal, and facilitate the above three developments ; and (5) more attention would be paid to the control of extraneous moisture in coal.

Mr. J. D. Peattie, Deputy Chief Engineer, Central Electricity Board, said that the electrical industry consumed annually some 24 million tons of fuel and was likely to consume more in the future. It was disappointing that consumers had not been more directly represented in connection with the preparation of the grading report, but it was hoped that the co-operation of consumers would be invited. At one time power stations could purchase their requirements in the open market ; the reputation of a particular colliery was sufficient guarantee of efficiency and quality. The need for classification was perhaps not quite so pressing then as now. Boiler plant was designed to give its output with the highest practicable economy, using fairly closely specified ranges of fuel ; it would not be so efficient if an attempt were made to consume fuels of unsuitable characteristics. The normal efficient life of boiler plant in power stations was previously 20 years ; that period had been extended to 25 years. To earn its interest and depreciation charges, it must be supplied uniformly with suitable fuel. Of 23 million tons consumed in stations under the control of the Central Electricity Board in 1944, less than 1½ million tons were graded ; the remaining 21½ million tons consisted of slacks. So the industry was deeply interested in any system of size nomenclature and classification of slacks. Again, of the 23 million tons, nearly 18½ million were burnt on stokers and only 4½ million in pulverised-fuel fired furnaces. The proportion of pulverised-fuel plant was rising, and it was anticipated that, when the total consumption had risen to some 27 million tons in the industry the weight fed to pulverised-fuel plant would have risen to 10 million tons. But the stokers would then still be using some 17 million tons. Provided other characteristics, such as moisture content, ash content and composition, ash fusion temperature, volatile content and friability were correct, fines could be used in pulverised-fuel plant, and the grading of smalls was perhaps less important than for stoker plant. In pulverised-fuel plant the grading affected mainly the preparation plant. It was not possible to consume efficiently any quality of coal in a pulverised-fuel fired furnace, or to obtain the necessary output from the pulverising mills. Difficulties had been experienced with stoker-fired plant since 1939 because of the increased proportion of fines, particularly below ⅛-in. The speaker disagreed with the proposal to admit any individual consignment outside the specified range and also with the proposal to limit the application of the system to the fuel as loaded at colliery screens ; the real interest of the coal industry should lie in service to the consumer.

Mr. P. A. H. Elliot, Director, Combustion Appliance Makers' Association, said the Association, after consultation with member firms making coal-burning appliances for domestic, industrial and marine purposes, had found that there was complete agreement as to the desirability of implementing the report with as little delay as possible. The demand for coal and the prices obtained in the past had been more influenced by size than by any other factor.

Elaborating the attitude and policy of the appliance makers, he said there had been no standard nomenclature whereby the size of coal could be defined, and unless the production programme of the coal industry and the development of the appliance industry proceeded hand-in-hand, it was useless to talk about fuel efficiency. In 1935, more than 340 names or combinations of names were in use to indicate sizes. Makers and users were led to specify very narrow and definite grades, and there was little inducement to ascertain whether a wider range of sizes was permissible. Difficulties encountered during the war would largely have been avoided if there had been a national sizing and grading of coals. He ventured to tender the advice to the National Coal Board that if it encouraged the design and installation of large numbers of appliances which would create demands for particular forms of fuel, it must be prepared to continue to make those forms of fuel available. Some way must be found of planning both the policy of the coal industry and of the appliance makers to harmonise with the requirements of the consumers.

When the agreed nomenclature and sizing had been established and adopted by the coal producers, it would be necessary to study the technical requirements of the appliances and to ascertain the range of sizes over which a given appliance would maintain its highest efficiency. It was of interest to note from the Statistical Digest, 1945, that 32·7 million tons of graded coals—this excluded large coal, hards and cobbles—were produced in the year 1945. Roughly speaking, 50 per cent. of the graded coal went to general industry, 30 per cent. to gasworks, and 6 per cent. to electricity, coke ovens and the domestic market. There were 30 million tons of washed slacks available per annum ; general industry only received 25 per cent. of the total, 50 per cent. being absorbed by the coke-oven industry, and 20 per cent. by electricity undertakings.

Mr. B. Samuels suggested that one of the greatest difficulties was the inconsistency of the supplies of coal, not only in respect of size, but of other characteristics, which, it was hoped, would be dealt with in due time. In his view, the Cinderella of coal consumers was the water-tube boiler user. The art of burning coal under a water-tube boiler was sufficiently developed to enable it to handle " any coal worthy of the name ". There was one limitation —that it must be capable of being delivered to the furnace mechanically. The grading proposals represented a very great step forward.

Indicating how the size of a fuel could influence the design and selection of a boiler plant, he said that in the smaller sizes, if the fuel did not contain too much fines, there was no need to go to the expense of forced-draught installations ; but if the coal contained a lot of fines, forced draught became necessary. Broadly speaking, a natural-draught stoker could take coal containing about 25 per cent. through ⅛-in. ; with forced draught the coal could contain 35 per cent. through ⅛-in. almost invariably, and in very many cases the percentage could be higher. In the case of the large archless furnaces, large coal could give rise to a good deal of trouble. Inconsistency of supplies had made it necessary to instal much larger or more boilers than would otherwise have been necessary. Urging that, in the preparation of coal for the market, consideration be given to blending, Mr. Samuels mentioned a large installation in London where there were facilities for mixing coal supplies. The result of that mixing was a very happy one, for the engineer could use coals neither of which would burn satisfactorily by itself, but which provided a perfect fuel when mixed. Close grading, from the water-tube boiler point of view, was not a very serious matter.

Dr. E. S. Grumell: It is very gratifying to hear today that one of the recommendations made at the conference organised by the Institute of Fuel in Manchester in February, 1945, namely that the size and nomenclature should be limited and standardised, has been carried a substantial stage further by a body on which so many of the interested parties were represented.

The whole problem of the preparation of coal requires complete review and revision in the light of modern methods of production underground, modern developments in cleaning plant, modern methods of marketing and distribution, and modern and future methods of utilisation.

The Manchester Conference was mentioned in stressing the lack of a system of uniform deliveries. No consumer wants 10 to 100 or more different coals. He wants consistent quality and size. With the knowledge which is now available, and with the brains which we have on our new National Coal Board, it should not be difficult to improve vastly on the pre-war system. Coal preparation must be so organised that it is carried out with the minimum capital and running costs and with a minimum loss of valuable heating units.

It has been stated on good authority that heating units equivalent to no less than 7 million tons of coal are annually discarded to the tip under normal practice. Admittedly some of these heat units are contained in coal of poor quality and high in ash content, but in the last week our works manager from the Punjab in India informed me that his regular supply of coal contained 40 per cent. of ash, and he used that efficiently in boiler plant designed on the sandwich system. He said that he could burn coal of any quality whatsoever. The greater part of this 7 million tons of coal could be recovered, and it would pay to recover it at the present price of coal. Specially designed plant and special location would be needed.

The time is long overdue when producers, consumers and appliance-makers should meet and discuss their respective difficulties, both technical and commercial, in order that our chief national asset, coal, may in future be prepared and utilised with the maximum economy.

Sir Charles Ellis (Member of the National Coal Board), summing up the session, noted that the report of the Coal Grading Committee had received general approval from every angle and said that it formed the essential prerequisite for a fair price structure. The report was not necessarily the final step but it opened up a new field and offered possibilities of development provided there was the will and enthusiasm for further progress. Measurements meant little scientifically unless the probable error of measurement was known ; those who framed this report were to be congratulated on introducing this feature, the proportion of undersize or fines corresponding to the probable error. The National Coal Board was in sympathy with the underlying objects of the report, namely a system of sizing, classification and nomenclature based on good practice which would meet the requirements of producers and consumers. The report would be examined by the Board's organisation as a whole when it had been established.

Written Discussion

Mr. John H. Anderson wrote that coal suffered more deterioration between leaving the screens and arriving at consumers' premises than at any other time. Among the reasons for this were segregation, freezing (which prevented the wagons from being completely emptied and caused excessive moisture which thawed on board ship and made the bottom layers of coal exceedingly wet), abrasion during shunting and by careless dropping of grabs on the coal or due to poor design of grabs and by dropping coal from grabs at too great a height. The writer suggested that coal after leaving the screens should be handled with care, avoiding shocks and high drops, and that handling should be reduced to the minimum.

Mr. A. S. Roxburgh wrote pointing out that in the report all the emphasis was placed on sizing, whereas other properties, especially ash content and calorific value, were essentially a part of " grading ". He regarded the supply of coal of regular quality as being of first-class importance for the maintenance of production in industry.

Mr. R. Cecil Smart wrote that modern fuel requirements involved preparation of fuels having controlled or standard thermal values. There had been too much emphasis on the interests of the producer of coal and in future the requirements of the user must be studied. Coal must be used with the utmost efficiency, but in the past the policy of the coal industry had been based on wasteful utilisation. Even today, the coal industry did not fully appreciate the information disclosed by the Coal Survey of the Fuel Research Board. Efficiency of coal utilisation was not concerned only with sizing but also with the preparation of clean fuels.

Mr. James A. Lacey wrote : Is it the intention to continue the production of unscreened and run-of-mine coal ?

National Coal Board (Marketing Department) replied : No immediate changes are likely to be introduced, but in the future it may be that the marketing of unscreened coal will be limited to consumers who express a particular preference for it.

Mr. A. P. Cooney (Dublin) wrote : Now that the committee has got so far, may generating station engineers hope that they will go further and in addition to grading investigate the possibility of evolving a " figure of merit " system which would be based on analysis, size, firing quality, handling quality, price, fusion point, etc. ? Some central stations such as ourselves are working with such a system, but the collection, pooling and issuing of such information by a central board would produce better results and make blending less difficult.

National Coal Board (Marketing Department) replied : A new system of price fixation will no doubt engage the attention of the National Coal Board in due course, but no early changes of the kind suggested by Mr. Cooney can be anticipated.

End of Volume II

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